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MARINE SANITATION SYSTEM DEMONSTRATION

Edmund L. Kaminsky, et al

Delaware River and Bay Authority

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Marine Sanitation System Demonstration

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A "flow-through" physical-chemical marine sanitation system capable of providing a high degree of secondary treatment was successfully demonstrated in the laboratory and on board the Delaware River and Bay Authority's Cape May-Lewes Ferry. Effluent performance goals of suspended solids and BOD_5 less than 50 mg/l and coliform bacteria count less than 240 MPN/100 ml were met. Following promulgation of the Environmental Protection Agency's "No Discharge" standard, the system (without the addition of any treatment processes) was also tested in a recycle mode by recycling the treated effluent for toilet flushing purposes. On the first recycle day, the suspended solids and BOD_5 remained at the "flow-through" levels. With each succeeding day the suspended solids increased only slightly, but the BOD_5 increased to values ranging between 140 and 400 mg/l. Coliform bacteria count was less than 10 MPN/100 ml. The color of the recycled water changed from clear to a gray milky appearance. A noticeable ammonia odor appeared on the second day. Ammonia nitrogen levels were in the 50-460 range. The ammonia can be removed by air stripping or breakpoint chlorination, and the increased BOD_5 levels can be reduced by chemical oxidation. (EPA)

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MARINE SANITATION SYSTEM DEMONSTRATION

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ABSTRACT

A "flow-through" physical-chemical marine sanitation system capable of providing a high degree of secondary treatment was successfully demonstrated in the laboratory and on board the Delaware River and Bay Authority's Cape May-Lewes Ferry. Effluent performance goals of suspended solids and BOD_5 less than 50 mg/l and coliform bacteria count less than 240 MPN/100 ml were met. Following promulgation of the Environmental Protection Agency's "No Discharge" standard, the system (without the addition of any treatment processes) was also tested in a recycle mode by recycling the treated effluent for toilet flushing purposes. On the first recycle day, the suspended solids and BOD_5 remained at the "flow-through" levels. With each succeeding day the suspended solids increased only slightly, but the BOD_5 increased to values ranging between 140 and 400 mg/l. Coliform bacteria count was less than 10 MPN/100 ml. The color of the recycled water changed from clear to a gray milky appearance. A noticeable ammonia odor appeared on the second day. Ammonia nitrogen levels were in the 50-460 mg/l range.

The ammonia can be removed by air stripping, ion exchange, or breakpoint chlorination, and the increased BOD_5 levels can be reduced by chemical oxidation.

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SECTION I

CONCLUSIONS

A physical-chemical marine sanitation system capable of providing a high level of secondary treatment was demonstrated in the laboratory and aboard the Delaware River and Bay Authority's Cape May-Lewes Ferry. The results of the tests showed the following:

1. Laboratory tests with fresh domestic sewage demonstrated that the system met the performance goal of producing an effluent with suspended solids and BOD_5 less than 50 mg/l and a coliform bacteria count less than 240 MPN/100ml.

2. Shipboard tests demonstrated that the system met the performance goal.

3. The marine sanitation system was converted to a recirculating system (without any additional treatment processes) to meet the Environmental Protection Agency's "No Discharge" vessel standard and reduce maintenance on the ship's plumbing system associated with sea water flushing. A series of five-day shipboard tests in a recycle mode was performed which showed that the suspended solids in the recycled flush water increased from less than 50 mg/l on the first day to values ranging between 60 and 100 mg/l by the fifth day; that the BOD_5 increased from approximately 50 mg/l on the first day to values ranging between 140 and 400 mg/l by the fifth day; and that a noticeable ammonia odor appeared during the second day. The appearance of the recycled flush water varied from a slight milky color on the first day to a milky gray on subsequent days. Coliform bacteria count remained less than 240 MPN/100 ml throughout each five-day test, and the chlorine residual in the recycle tank was approximately 0.5 to 1.0 mg/l.

4. Results of the recycle tests provide the basis for system modifications which can upgrade treatment to insure an effluent that is clear, odorless, or otherwise acceptable for recirculation as flush liquid.

5. Data collected during the program demonstrated the system's performance reliability and maintainability. Level gages shorted out on two occasions, and the rubber stator in one of the pumps required replacement due to

excessive wear. Apart from the down time caused by these malfunctions, the system operated reliably 16 hours per day.

6. During the laboratory phase of the program, two problems were encountered which were successfully resolved in the initial stages. The first was finding the proper type of sewage (fresh and aerobic) for test purposes. The second was plugging of the centrifuge due to fibrous material which passed through an in-line comminuter up-stream of the centrifuge. This problem was resolved by substituting a vibrating screen for the comminuter. Two operational problems arose during shipboard tests. During the peak flow periods in the peak season, the volume of wastewater discharged to the sanitation system exceeded the storage capacity of the collection tank. This was caused by a flow of 6,000 gpd imposed on a system designed for 5,000 gpd, aggravated by stuck toilet valves due to sand sucked from the bottom of Delaware Bay. The other operational difficulty encountered was flooding of the solids holding tank on three occasions caused by pressure surges to the sanitation system during the maintenance shift.

7. The initial cost of the marine sanitation system (5,000 gallon-per-day size) was $40,000.00. Installation cost, including vessel modifications, was $26,000.00. During the three-month peak season on the Cape May-Lewes Ferry, the chemical costs were approximately $120 per month, including fuel costs of $20 per month for the diesel generator which was used because alternating current was not available on the vessel. For the remainder of the season, chemical costs would be approximately $25 per month, with the fuel costs remaining constant at $20 per month. Cost of disposing of accumulated solids by sewage tank truck was $80 per month. Operation and maintenance of the system did not require additional manpower costs, since these functions were handled by existing crews in addition to their normal duties.

8. Although solids holding with periodic pump out at dockside was the technique used for solids disposal during the program because it was a convenient method, on-board drying of the solids with subsequent disposal of a sterile cake would be a feasible technique which can be used. This method would be especially helpful for vessels which do not dock every night as does the Cape May-Lewes Ferry.

SECTION II

RECOMMENDATIONS

The test program successfully demonstrated a "flow-through" marine sanitation system capable of providing a high degree of secondary treatment. In view of the "No Discharge" standards promulgated by the U. S. Environmental Protection Agency on June 23, 1972, however, it is recommended that this available shipboard test vehicle be utilized for additional demonstrations. These would include the following:

1. The addition of relatively simple known treatment processes to the existing system to provide a no-discharge system, with recycling of an aesthetically acceptable treated sanitary wastewater. It is recommended that these processes be incorporated into the existing system aboard the Cape May-Lewes Ferry and demonstrated when the vessel resumes operation in the spring of 1973.

2. It is further recommended that the information and experience gained on this program be used to design, fabricate, and install another marine sanitation system aboard a Government vessel (such as a Corps of Engineers vessel) to provide a test bed for additional data. Performance data would be obtained for the following processes: (1) "primary" treatment (separation of solids by means of a vibrating screen only, with disinfection and discharge of the partially clarified wastewater); (2) "improved primary" treatment (same as above with the addition of centrifuging prior to disinfection); (3) "secondary" treatment (screening plus centrifuging plus carbon column treatment plus disinfection, with the tests performed over an extended period of time, and various types of carbon evaluated to determine the type best suited for shipboard wastewater treatment); (4) "no-discharge, recycle" treatment, also over an extended period of time. On-board drying of the sludge would be a major item evaluated.

SECTION III

INTRODUCTION

This report presents the results of a marine sanitation system demonstration performed under U. S. Environmental Protection Agency Project No. 15020 GYM, awarded to the Delaware River and Bay Authority. The system was designed, developed, and patented by Marland Environmental Systems, Inc. (formerly Pollution Control Industries, Inc.), located in Wayne, Pennsylvania, and was tested both in the laboratory and on the Delaware River and Bay Authority's Cape May-Lewes Ferry.

The sanitation system tested is a physical-chemical system capable of providing a high degree of secondary treatment, that is, one providing a reduction of suspended solids in excess of 90 percent and a reduction in BOD_5 in excess of 80 percent. Functionally, this was accomplished by first separating the suspended solids in a two-stage mechanical operation, consisting of a vibrating screen and a centrifuge, without any accompanying chemical treatment, and then reducing the dissolved organics by means of carbon columns. The wastewater was chlorinated before and after carbon column treatment. Separated suspended solids were stored in a solids holding tank which was periodically pumped out to a sewage tank truck brought aboard the vessel while it was docked at night, with subsequent on-land disposal of the sludge.

The system was designed as a "flow-through system", that is, one which discharges a treated effluent overboard. The performance goal was a treated effluent with suspended solids less than 50 mg/l, BOD_5 less than 50 mg/l, and a coliform bacteria count less than 240 MPN/100 ml. The original objective of this program was to demonstrate the system in this mode of operation. After promulgation in June 1972 of the Environmental Protection Agency's "No Discharge" standards, the program was revised to include the evaluation of the system in a recycle mode, using the treated effluent for sanitary flush water. To accomplish this purpose, a recycle water storage tank was added to the originally designed system. Testing in the recycle mode was then conducted to determine the effects of such recycling on the treated wastewater, i.e., buildup and effect on treatment of constituents in the wastewater.

Land-based testing was completed early in the program, using a prototype laboratory system, in order to demonstrate system feasibility and obtain design verification data. Shipboard testing aboard the Cape May-Lewes Ferry was successfully conducted during the months of July, August, and September 1972 in both the overboard discharge and recycle modes.

The Cape May-Lewes Ferry is an ocean-going vessel used for transporting vehicles and passengers. Designed to carry up to 800 passengers per trip, it makes four round trips each day across Delaware Bay from Cape May, New Jersey to Lewes, Delaware. Time in transit on each single crossing is 75 minutes, with a departure from Lewes scheduled 2 hours after departure from Cape May. The first trip departs from Cape May at 7:30 a.m., and the last trip arrives at Cape May at 10:30 p.m. The maintenance shift runs from 10:30 p.m. until 6:30 a.m. the next morning.

SECTION IV

SYSTEM DESCRIPTION

The Marland physical-chemical marine sanitation system treats wastewater by first removing suspended solids in a two-step physical operation, then reducing the dissolved organics by adsorption on activated carbon columns, and disinfecting the effluent prior to discharge overboard. The system process flow diagram is shown in Figure 1. The total wastewater on the Cape May-Lewes Ferry consists of sewage from toilets and urinals, washwater from sinks and showers, and wastewater from the snack bar. The major portion of the total wastewater consists of feces and urine flushed down the toilets and urinals. The contribution from the showers is negligible, since these are seldom used by the crew. Wastewater from the snack bar first passed through a grease removal unit before it joined the other components of the total wastewater flow. Immediately upstream of the system, an emergency raw wastewater bypass valve was located to bypass the flow overboard in the event of system malfunction.

The wastewater enters the system through a gross solids separator (a vibrating screen), which immediately removes large particles and discharges them into a solids holding tank. This technique also eliminates the BOD_5 which would be immediately released to the wastewater if the large particles broke open or were comminuted. In addition, the partially clarified wastewater is more easily pumped and treated. Also, the separated solids are of relatively high density. The wastewater which passes through the gross solids separator accumulates in a collection tank sized to meet the anticipated surge loads for the vessel. When the wastewater reaches a predetermined upper level, the wastewater is pumped at a constant flow rate to a fine solids separator. When a predetermined low level is reached, pumping is automatically stopped, and the additional wastewater accumulates in the collection tank. Fine solids separation is obtained by a centrifuge, which removes most of the remaining suspended solids and discharges them into the same solids holding tank used to accumulate solids from the gross solids separator.

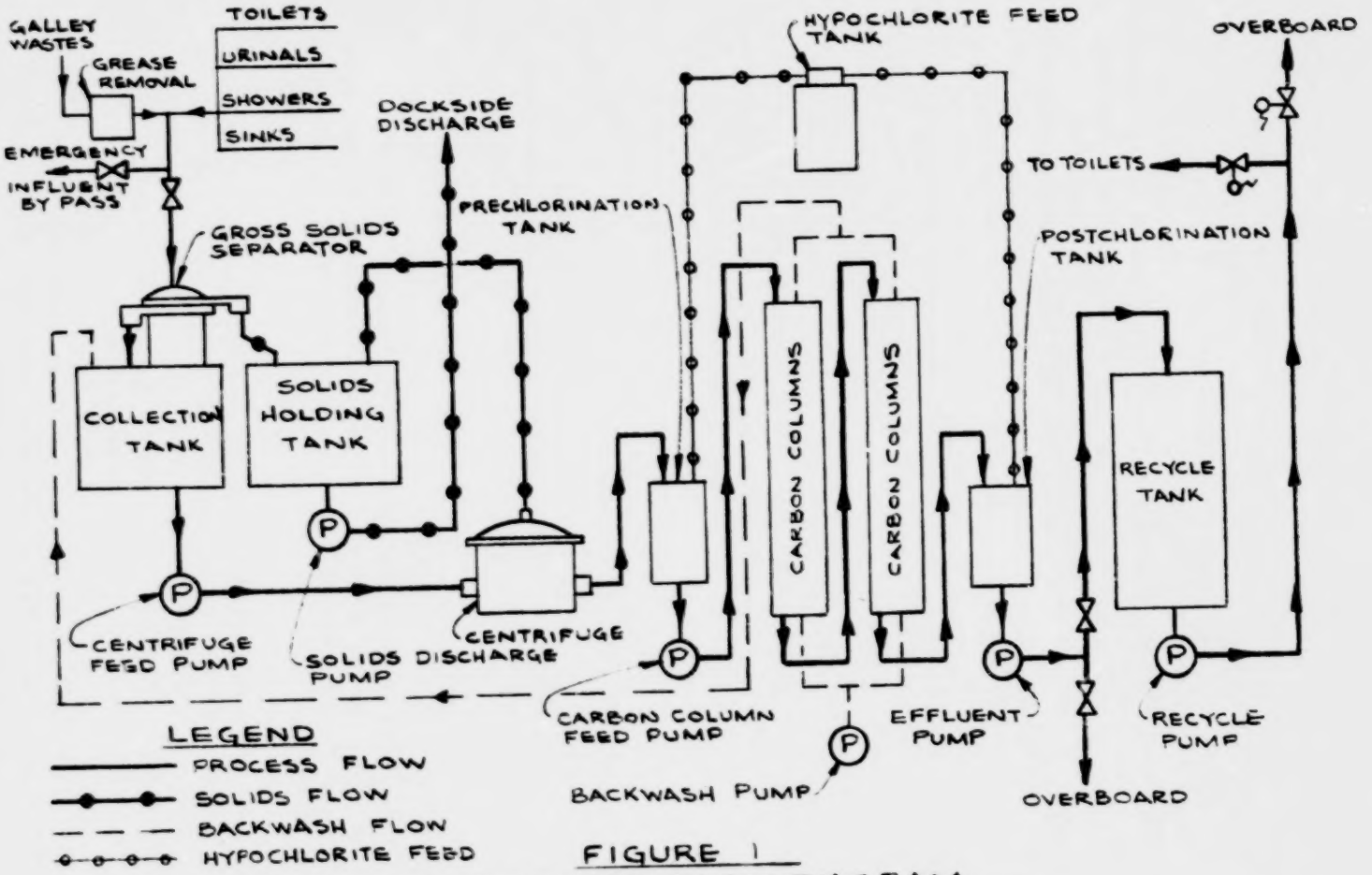


FIGURE 1

PROCESS FLOW DIAGRAM

MARLAND MARINE SANITATION SYSTEM

ABOARD THE CAPE MAY-LEWES FERRY (EPA PROJECT #15020 GYM)

The centrifuge effluent is prechlorinated and disinfected in a disinfection tank prior to carbon treatment. The original intent of this prechlorination was to reduce the bacterial activity on the carbon columns in order to prevent possible plugging of the columns, which would then require frequent backwashing. From the disinfection tank the wastewater is pumped through columns of activated carbon, operating in a packed-bed downflow mode, where most of the dissolved organics are removed from the wastewater stream. The discharge from the carbon columns is then postchlorinated, and the treated effluent is then discharged overboard.

During the program it was observed that the discharge from the carbon columns was anaerobic, as indicated by the odor of hydrogen sulfide in samples taken immediately downstream of the columns. This result confirmed the experience of others (references 1 and 2) that anaerobic biological activity takes place in the carbon beds. This activity is beneficial in that it increases the total capacity of the carbon beds for removing dissolved organics, that is, it increases the life of the carbon beds. The hydrogen sulfide is eliminated in the postchlorination stage, but this demands some of the chlorine intended for final disinfection. Although the existence of anaerobic biological activity in the carbon beds makes the necessity for prechlorination questionable, prechlorination was used throughout the program.

The solids holding tank is sized to retain the separated solids prior to their ultimate disposal. For the Cape May-Lewes Ferry the solids were periodically pumped to a sewage tank truck brought aboard the vessel during the maintenance shift and ultimately disposed of at a sanitary landfill.

The carbon columns are backwashed each day during periods of low flow. On the Cape May-Lewes Ferry this was done during the maintenance shift, when the vessel was docked for the night. The backwash water is pumped to the collection tank and then reprocessed through the system.

The design described above was the one demonstrated under this program. Water for flushing was sea water pumped from Delaware Bay. After promulgation of the

Environmental Protection Agency's "No Discharge" standards in June 1972, a program revision was made to include an evaluation of recycling the treated effluent for sanitary flush water, without any additional treatment processes, in order to determine the effects of such recycling on build-up of contaminants in the recycled effluent. To accomplish this purpose, a recycle storage tank was placed aboard the vessel which was initially filled with city water, and the effluent was recycled through this tank.

SECTION V

SYSTEM DESIGN AND INSTALLATION

For installation aboard the Cape May-Lewes Ferry, the Marland marine sanitation system was designed as a 5,000 gpd "f. ow-through" system. The sizing was based on flow measurements taken aboard the ferry for an entire day at the vessel's sanitary pump and fresh water pump. The flows were increased by the ratio of passengers during the peak passenger day in August 1970 to passengers aboard the vessel on the flow measurement day in June 1971. The flow measurement and prediction data and the procedure for selecting the flow rate and sizing the collection tank are presented in detail in Appendix A-1. From these data it was established that a system flow through rate of 5 gpm and a collection tank of about 600 gallons would be adequate. This information was then used to size two systems - a prototype laboratory system and the shipboard system. The prototype system was used for early land-based testing to demonstrate system feasibility and to obtain design confirmation data on suspended solids and BOD_5 removals while design and fabrication of the shipboard system were in progress.

The major components of the prototype system are listed in Table 1. Except for the pilot carbon column unit, all components were full scale hardware. The gross solids separator selected was a 24-inch-diameter SWECO vibro-separator, the particular size chosen being based on an estimate of 25 gpm peak flow rates on the vessel. The fine solids separator selected was a Westfalia SA7-06 Desludger disc-type centrifuge. Based on highly successful tests for suspended solids and BOD_5 removals (described in Section VI of this report) with the prototype system at the design flow rate, the same solids separation components were selected for the shipboard system.

The major components of the shipboard system are listed in Table 2. A 600-gallon collection tank was provided. From the prototype system tests is was estimated that approximately 20 gallons of solids would be produced each day aboard the ferry, and a solids holding tank of 400 gallons capacity (operating volume of 350 gallons) was

TABLE 1

PROTOTYPE SYSTEM
MAJOR COMPONENT LIST

1. Gross Solids Separator

SWECO Vibro-Separator, 24" diameter, with 64- and 105-mesh screens

2. Fine Solids Separator

Westfalia SA7-06 Desludger Centrifuge

3. Carbon Columns

Four column pilot unit, each column 5" diameter and 6' high, containing 0.4 cu. ft. of Calgon Filtrasorb 300 (8 x 30 mesh)

4. Tanks

a. Receiving: 1,200 gal.

b. Collection: 600 gal.

c. Disinfection: 85 gal.

5. Process Pumps

Moyno FS 33

TABLE 2

SHIPBOARD SYSTEM
MAJOR COMPONENT LIST

1. Gross Solids Separator

SWECO Vibro-Separator, 24" diameter, with 64-mesh screen

2. Fine Solids Separator

Westfalia SA7-06 Desludger Centrifuge

3. Carbon Columns

Four carbon columns, arranged in parallel series. Each column 14" diameter and 6' high, containing 120 lb. (4 cu. ft.) of Calgon Filtrasorb 300 (8 x 30 mesh).

4. Tanks

a.	Collection:	600 gal.
b.	Solids Holding:	400 gal.
c.	Disinfection:	75 gal.
d.	Surge:	55 gal.
e.	Recycle Storage:	1,400 gal.

5. Pumps

a. Process: Moyno FS33
b. Fresh Water Feed: Moyno FS33
c. Backwash: Moyno FS67
d. Recycle: Moyno FS67
e. Solids Discharge: Marlow 3CR18EL
f. Chlorine Metering: Wallace & Tiernan 94-110

6. Motors

a. Vibro-Separator: Baldor, 1/3 hp
b. Centrifuge: Louis-Allis, 5 hp
c. Process Pumps: Baldor, 1/2 hp
d. Fresh Water Feed Pump: Baldor, 1/2 hp
e. Backwash Pump: Baldor, 2 hp

TABLE 2
(Continued)

6. Motors (continued)

f. Recycle Pump: Baldor, 2 hp
g. Solids Discharge Pump: Baldor, 3 hp

7. Diesel Generator

Hol-Gar Model 33D6-WRD, 120/240 VAC, 3Ø

provided to minimize the number of times the solids would be pumped out (about once every 2-1/2 weeks).

The carbon columns were sized to provide a carbon contact time of 25 minutes, based on gross carbon volume, and four columns were used, arranged in parallel - series, because this arrangement yielded a practical configuration which met desirable length-diameter ratio, superficial velocity, and expansion during backwash.

The electrical power aboard the Cape May-Lewes Ferry is direct current. Since it was desired to use alternating current components, a diesel generator was selected to provide approximately 10 kilowatts power with both 240 and 120 volt, 3 phase, 60 Hertz circuits. Except for carbon column backwash and sludge disposal, all functions were automatic once the system was turned on, and a power and control cabinet was provided to perform these functions.

Photographs of the system assembled in the shop prior to shipment are shown in Figures 2 and 3. Figure 2 shows the solids separation and storage components, some of the process pumps, and the control cabinet. Figure 3 shows one of the hypochlorite tanks, a process pump, the post-chlorination surge tank, the backwash pump, and two of the four carbon columns positioned in the carbon column support structure.

The system was installed aboard the S. S. DELAWARE, in an essentially empty mid-ship hold compartment located between the engine room and the boiler room, as shown in Figure 4. The spread-out arrangement was selected deliberately in order to expedite the taking of samples and providing easy access to all parts of the system, since a very large space was available, measuring approximately 18 feet by 20 feet, with extra space available for a diesel generator and a recycle tank on the other side of the vessel. Ceiling height was approximately 18 feet.

The dry weight of the system, including the recycle tank, was approximately 10,000 pounds and the wet weight approximately 31,000 pounds.

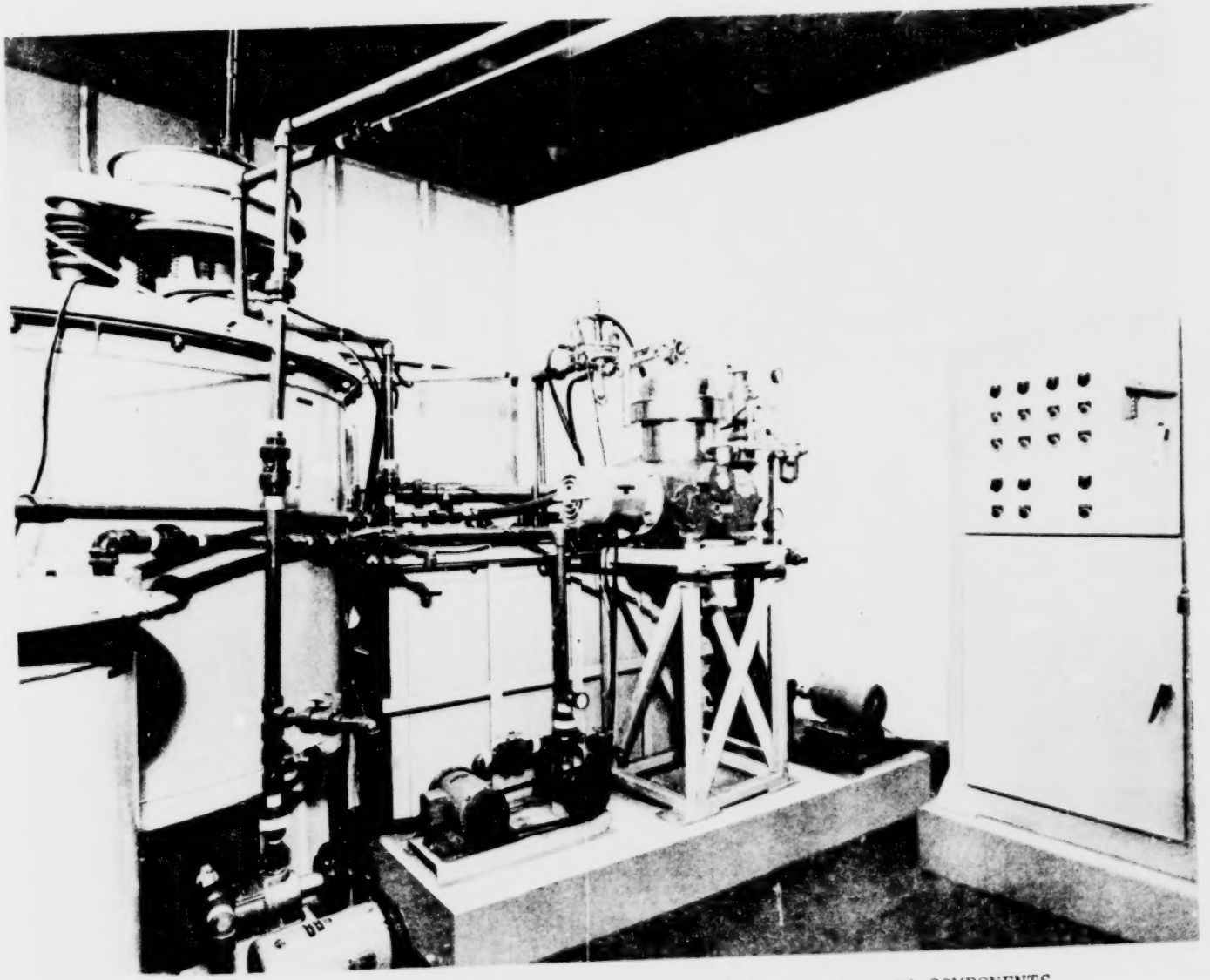


FIGURE 2: SUSPENDED SOLIDS REMOVAL AND STORAGE COMPONENTS OF CAPE MAY-LEWES FERRY SYSTEM

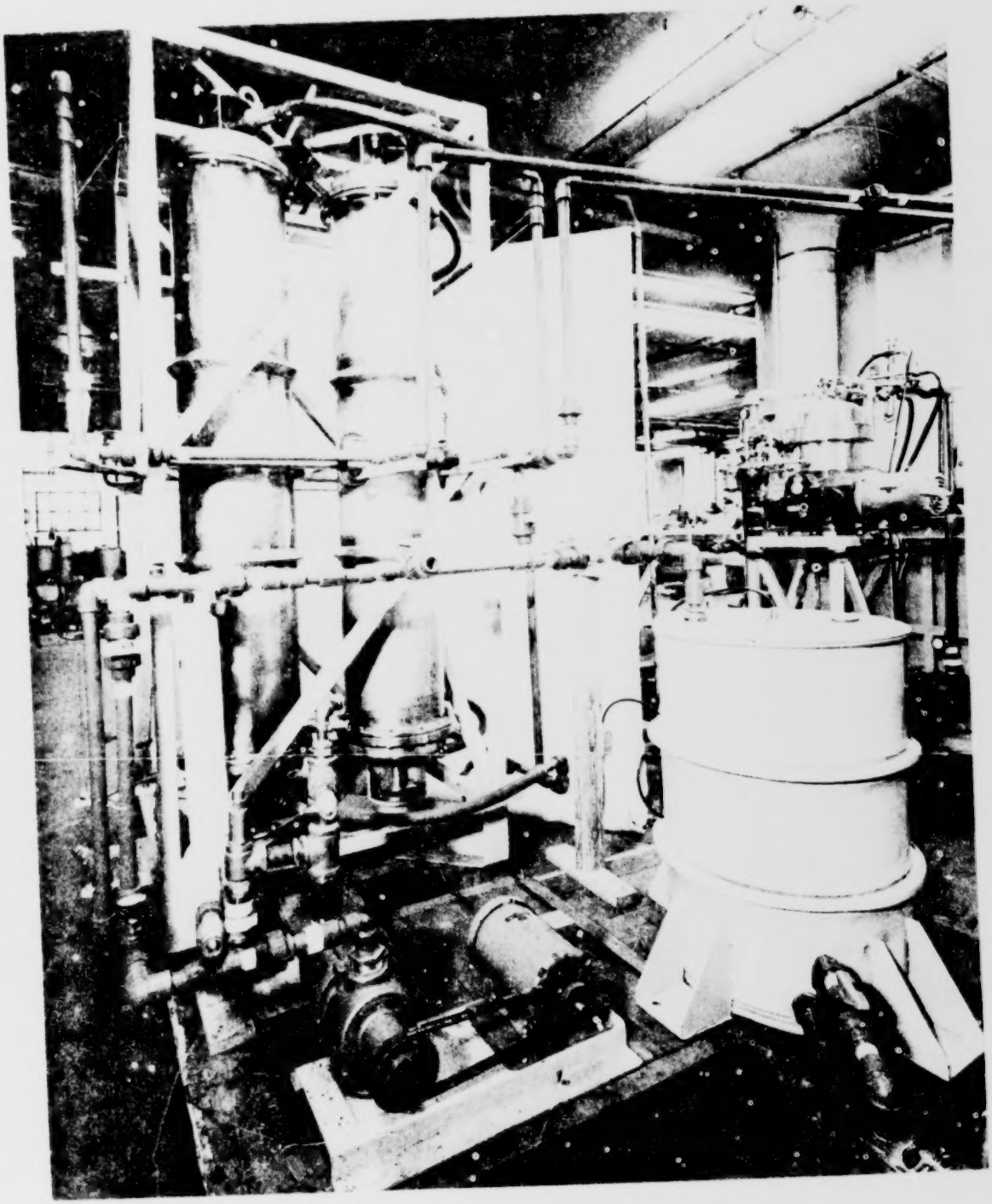


FIGURE 3

CARBON COLUMN AND POST-CHLORINATION COMPONENTS
OF CAPE MAY-LEWES FERRY SYSTEM

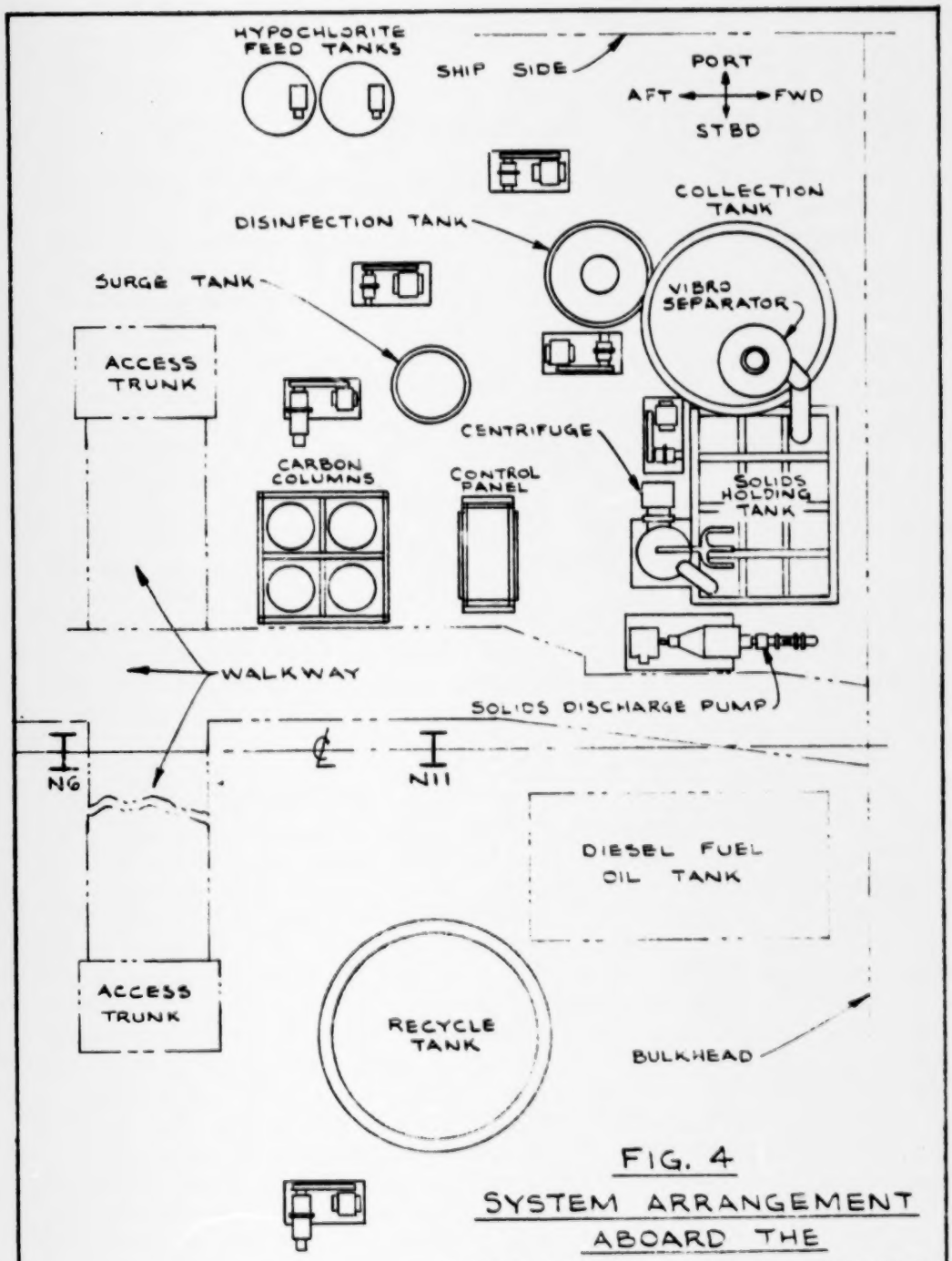


FIG. 4

SYSTEM ARRANGEMENT ABOARD THE CAPE MAY - LEWES FERRY

SECTION VI

SYSTEM PERFORMANCE

Prototype System Tests and Performance

The initial test period was primarily devoted to evaluating centrifuge performance in removing suspended solids from raw sewage. Based on the results of early tests conducted at the vendor's laboratory, a Westfalia SA7-06 centrifuge was selected for evaluation. The results of these early tests are summarized in Figure 5. Clarification tests on comminuted sewage, with and without prior chemical treatment, were conducted with a Westfalia SAMN-205 centrifuge. This machine is a scale model of the Westfalia SA7-06 Desludger, and results obtained at a given flow rate with the smaller machine can also be expected with the SA7-06 at a flow rate six times higher. The curves in Figure 5 show that prior chemical treatment is beneficial at lower flow rates, but that poorer results are obtained at higher rates, probably because the floc formed by the chemicals is broken up in the centrifuge at the higher rates. At the system design flow rate of 5 gpm through the SA7-06 (0.833 gpm through the SAMN-205), the suspended solids in the centrifuge effluent are 64 mg/l for untreated sewage and 45 mg/l with the addition of lime.

In the early stages of prototype testing, centrifuging was preceded by sewage comminution (a Franklin-Miller 3-inch-diameter in-line pipeline Delumper). The test procedure employed was as follows: (1) On the morning of the test, raw sewage was pumped by a sewage tank truck either out of underground storage tanks or the inlet to a municipal treatment system, delivered to the laboratory, and pumped through the comminuter to a holding tank. (2) A test batch of sewage was pumped to a collection tank, from which it was pumped at a rate of 5 gpm, the ship system design flow rate, through the centrifuge. (3) Samples of both the feed and the centrate were taken and analyzed for suspended solids. Although the Delumper comminuted the sewage to a satisfactory size, it was not always capable of preventing fibrous material from entering the centrifuge. This resulted at times in the formation of a mat of solids across the desludging ports of the centrifuge which was not always ejected completely when the two bowls of the

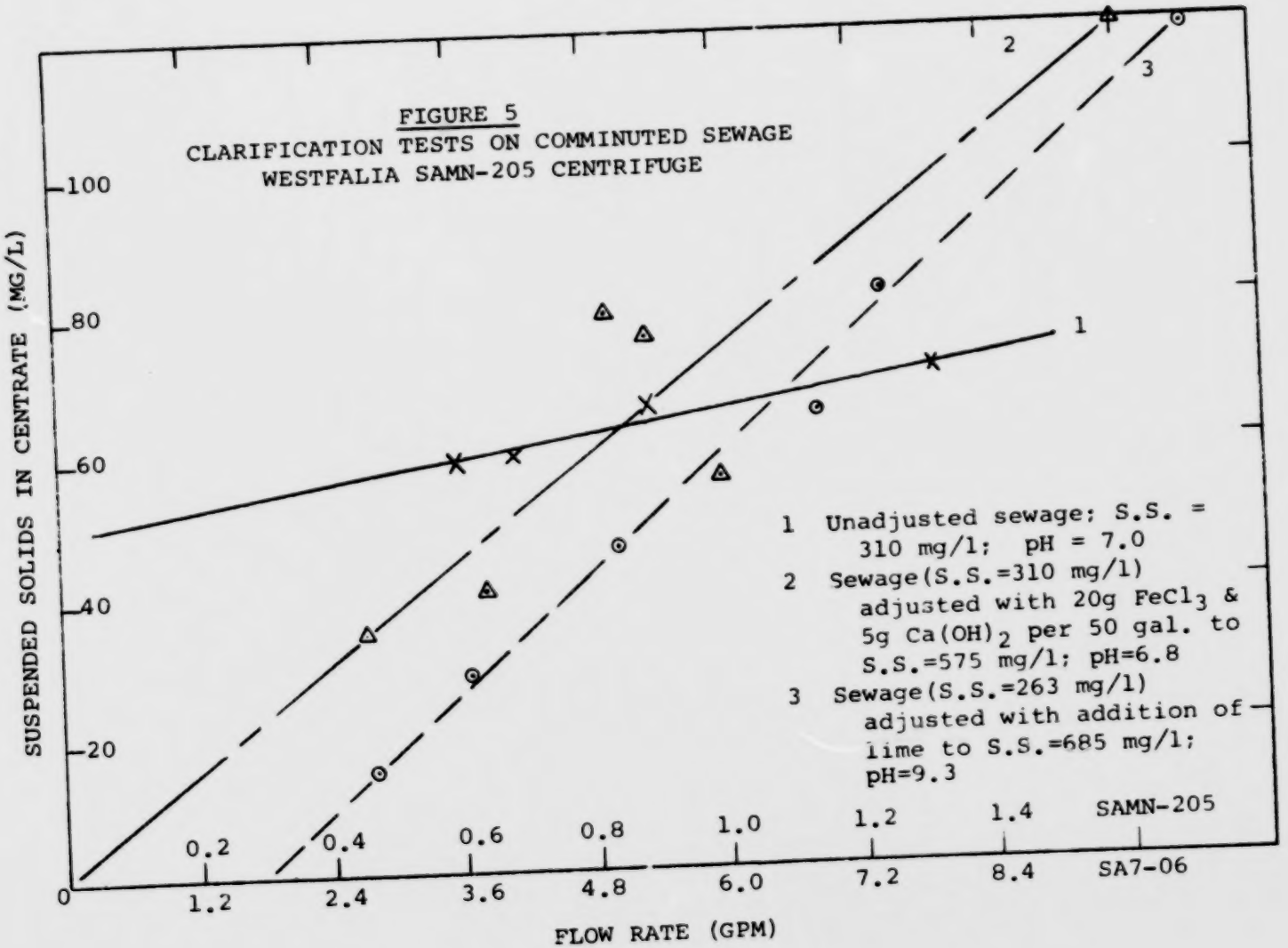


FIGURE 5
CLARIFICATION TESTS ON COMMINUTED SEWAGE
WESTFALIA SAMN-205 CENTRIFUGE
SUSPENDED SOLIDS IN CENTRATE (MG/L)
100
80
60
40
20
0
1
2
3
1 Unadjusted sewage: S.S. = 310 mg/l; pH = 7.0
2 Sewage(S.S.=310 mg/l) adjusted with 20g $FeCl_3$ & 5g $Ca(OH)_2$ per 50 gal. to S.S.=575 mg/l; pH=6.8
3 Sewage(S.S.=263 mg/l) adjusted with addition of lime to S.S.=685 mg/l; pH=9.3
0.2
0.4
0.6
0.8
1.0
1.2
1.4
SAMN-205
1.2
2.4
3.6
4.8
6.0
7.2
8.4
SA7-06
FLOW RATE (GPM)

centrifuge separated during the desludging cycle. The partially ejected mat prevented complete closure of the bowls following the desludging cycle, which resulted in bowl leakage. The problem was solved by eliminating the comminuter and substituting a SWECO vibro-separator upstream of the centrifuge. This device was tested with both 70 and 100 mesh screens. With the introduction of the vibro-separator, no further desludging problems were encountered, and when the centrifuge was dismantled following a series of tests, the bowl was always completely clean.

In addition to the prevention of desludging problems, the vibro-separator also provides another advantage. With this device, the gross suspended solids are immediately separated from the wastewater stream without break up of the solids. When gross solids are broken apart in a wastewater stream, BOD_5 is immediately released to the stream and goes into solution. This disadvantage of comminution of solids is eliminated by the use of the vibro-separator.

As part of the early test program, preliminary samples were taken of sewage discharged from the Cape May-Lewes Ferry. A break was made in one of the overboard discharge lines, and the sewage was collected in 55-gallon drums during the first trip. A sample was taken from the drums and analyzed. The results are presented in Table 3. The high value of total solids is due primarily to the presence of salts in Delaware Bay water, which was used for flushing. Although the suspended solids level (396 mg/l) is representative of values found during later shipboard testing, the BOD_5 level is relatively low. (See results of shipboard tests discussed later in this section of the report.)

Difficulties were encountered during early centrifuging tests in finding the right kind of sewage for test purposes. Since the wastes on the vessel discharge directly into the treatment system, the test sewage should be raw and completely aerobic. Most of the sewage taken from underground holding tanks was septic. Batches from the municipal plant also contained industrial wastes, and suspended solids loads were sometimes very high (values ranged from about 100 to 4,860 mg/l). The suspended solids removals

TABLE 3

RESULTS OF ANALYSIS OF
PRELIMINARY SAMPLE OF SEWAGE
FROM CAPE MAY - LEWES FERRY

PARAMETER	VALUE IN Mg/l
Total Solids	44,834
Suspended Solids	396
Dissolved Solids	44,438
Total Volatile Solids	8,998
Volatile Suspended Solids	272
Volatile Dissolved Solids	8,726
BOD_5 on Total Sample	180
BOD_5 on Filtered Sample	88

NOTE: Delaware Bay sea water used for flushing

obtained from these sewage batches, with and without chemical treatment prior to centrifuging, showed considerable scatter, regardless of chemical treatment. These early results are presented in Appendix A-2.

The proper sewage, fresh and raw, was finally obtained from an apartment complex known as English Village Apartments. The sewage was collected immediately upstream of the comminuter/bar screen assembly of the apartments' package sewage treatment system as the sewage flowed directly from the buildings to the treatment plant. Batches were always taken during the morning of a test run. With the proper sewage available, prototype testing was expanded to include not only suspended solids removal, but also carbon column treatment preceded by and followed by chlorination.

For each test run approximately 1,000 to 1,200 gallons of sewage were used. Grab samples were taken every 40 minutes, for a total number of 4 or 5 samples per location, and these samples were composited for analysis. Samples were taken of the feed, vibro-screen underflow, centrifuge effluent and carbon column effluent. The samples were kept on ice during the test period and delivered on ice to the analysis laboratory (a trip of approximately 30 minutes), where the samples were immediately prepared for analysis. All analyses were performed in accordance with approved EPA procedures in "Methods for Chemical Analysis of Water and Wastes," except (for the prototype system) for the coliform tests, which were performed at the test facility using a Hach kit.

Suspended Solids and BOD_5 Removal

The results of 12 runs with English Village sewage, with no chemical additives, are summarized in Table 4, which lists the suspended solids and BOD_5 levels at various stages in the treatment process. From the highly favorable results of these tests, it was concluded that chemical treatment was not required. The suspended solids data are also plotted in Figure 6, and the BOD_5 data in Figure 7. The results of these tests show that the suspended solids in the effluent were always below the performance goal of 50 mg/l, and that the BOD_5 in the effluent was also always below the performance goal of 50 mg/l, except for two test

TABLE 4

SUMMARY OF PERFORMANCE - PROTOTYPE SYSTEM
ON FRESH DOMESTIC SEWAGE WITH NO CHEMICAL ADDITIVES
AT A FLOW RATE OF 5 GALLONS PER MINUTE

RUN NO.	SUSPENDED SOLIDS				BOD_5			
	F	SU	CE	CCE	F	SU	CE	CCE
1	482	348	27	12	165	130	-	26
2	-	172	17	16	180	104	65	10
3	144	78	47	10	107	-	60	23
4	306	172	20	10	86	-	40	18
5	648(1)	290	46	11	420(1)	360	358	67
6	124	75	20	9	118	76	50	12
7	360	148	26	10	130	101	35	30
8	130	120	5	2	78	127	15	3
9	434	282	67	18	440	375	114	47
10	258	256	45	24	172	173	103	35
11	132	124	38	4	145	128	69	33
12	151	112	27	21	212	163	120	61(2)

NOTES: All values in mg/l
Sewage Source: English Village Apts.
F Means Feed
SU Means Screen Underflow
CE Means Centrifuge Effluent
CCE Means Carbon Column Effluent

(1) Bread added to feed to raise BOD

(2) Result for single carbon column

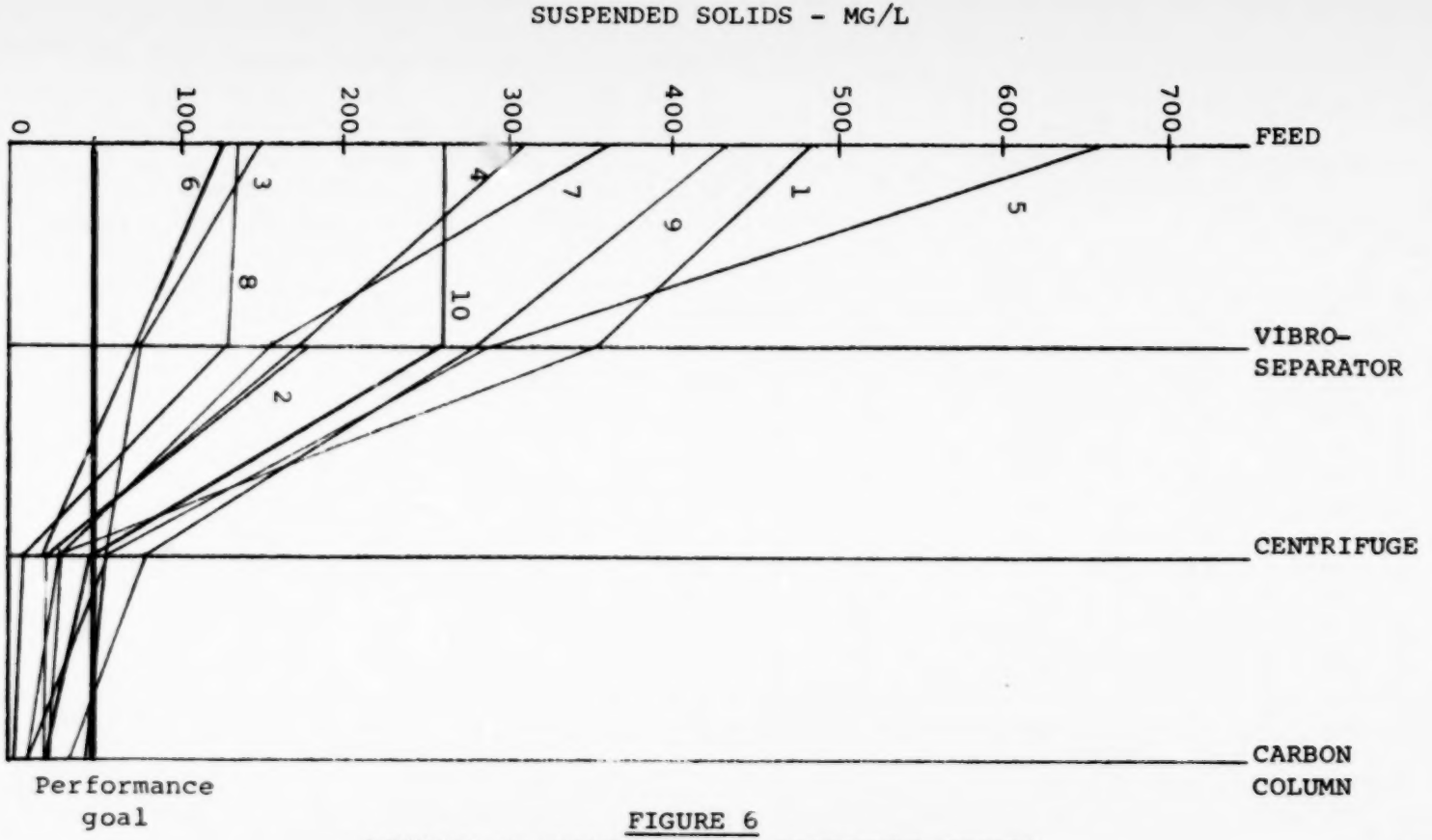


FIGURE 6

SUMMARY OF PERFORMANCE - PROTOTYPE SYSTEM
ON FRESH RAW SEWAGE WITH NO CHEMICAL ADDITIVES
AT A FLOW RATE OF 5 GALLONS PER MINUTE

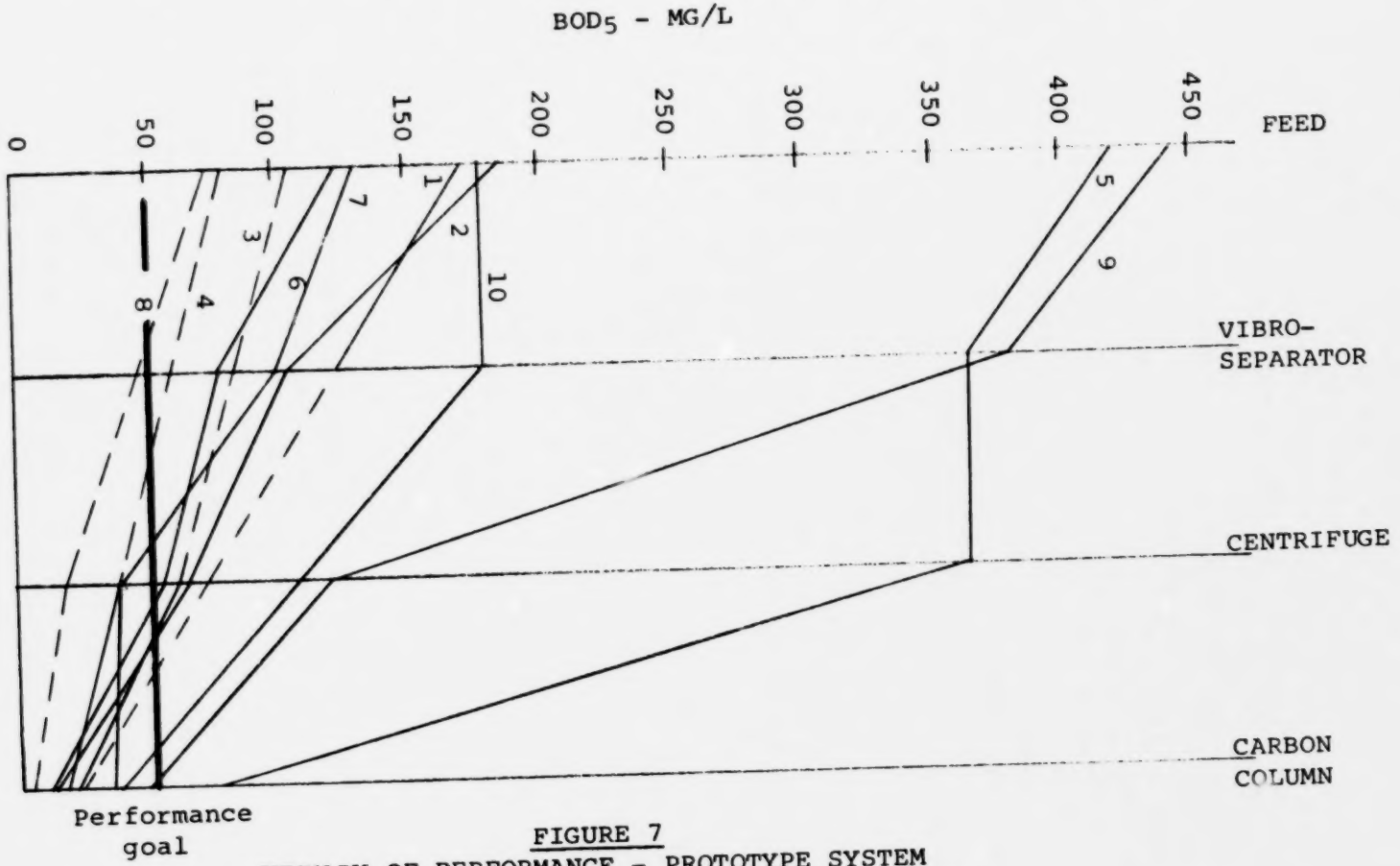


FIGURE 7

SUMMARY OF PERFORMANCE - PROTOTYPE SYSTEM
ON FRESH RAW SEWAGE WITH NO CHEMICAL ADDITIVES
AT A FLOW RATE OF 5 GALLONS PER MINUTE

runs (No. 5 in Table 4, where the BOD_5 level was artificially increased by adding pieces of bread to the sewage, and No. 12, where the BOD result is given for only one column rather than two columns in series). For Run No. 5, most of the BOD_5 was in the dissolved form. This can be seen in Figure 7, where the BOD_5 after the vibro-screen is only slightly less than the BOD_5 before the vibro-screen, even though Figure 6 shows a considerable reduction in suspended solids by the screen. It is also evident from Table 4 and Figure 6 that, except for Run No. 9, the suspended solids loading in the centrate was less than 50 mg/l, even before the filtering effect of the carbon columns. The first ten runs were made with fresh water sewage. In order to determine the effects of salt water on performance, Aqua-Biotic marine salts, distributed commercially by Aquarium Pharmaceuticals, Inc., were added to the fresh water sewage for Run No. 11. The salts contained in this mixture are listed in Appendix A-3. Only 150 gallons of the sea water sewage were tested. The results showed no substantial difference from the fresh water data, and from these very limited data, it was concluded that no differences would be expected in shipboard tests.

The percentage reductions in suspended solids and BOD_5 at the various stages in the treatment process are listed in Table 5 for the test runs of Table 4. For the 12 runs the average values of suspended solids reduction are 31.5% through the vibrating screen, 85.3% through the centrifuge, and 94.9% through the carbon columns. The average values of BOD_5 reduction are 20.6% through the vibrating screen, 51.7% through the centrifuge, and 81.7% through the carbon columns. All percentage reductions are based on the original values in the feed.

The carbon columns used for prototype testing were pilot columns 5 inches in diameter with a carbon bed depth of 3 feet. The columns were employed in the packed bed, down flow mode. A comparison between the pilot and vessel columns is given in Table 6. The vessel design is based on four columns arranged in parallel-series, as shown in Figure 8, providing a total carbon contact time of 25 minutes, based on gross carbon volume. With this arrangement, the vessel wastewater flow at 5 gpm is first split into two parallel streams of 2.5 gpm each, and each stream passes through two columns in series. Hence the contact

TABLE 5

PER CENT REDUCTIONS OF SUSPENDED SOLIDS AND BOD_5
PROTOTYPE SYSTEM

RUN NO.	SUSPENDED SOLIDS				BOD_5			
	F	SU	CE	CCE	F	SU	CE	CCE
1	-	27.8	94.5	97.5	-	21.2	-	84.4
2	-	-	-	-	-	42.2	63.9	87.9
3	-	45.8	67.3	93.0	-	-	43.9	78.5
4	-	43.9	90.3	97.0	-	-	53.5	79.1
5	-	55.3	93.0	98.3	-	14.3	14.8	84.1
6	-	39.5	84.0	92.9	-	35.6	57.6	89.9
7	-	59.0	93.0	97.3	-	22.3	73.0	77.0
8	-	7.7	96.0	98.3	-	NOT COUNTED		
9	-	35.0	84.6	96.0	-	14.8	74.1	89.4
10	-	0.8	82.5	90.6	-	0	40.1	79.6
11	-	6.1	71.3	96.9	-	11.7	52.4	77.3
12	-	25.8	82.0	86.0	-	23.1	43.5	71.2
AVE.	-	31.5	85.3	94.9	-	20.6	51.7	81.7

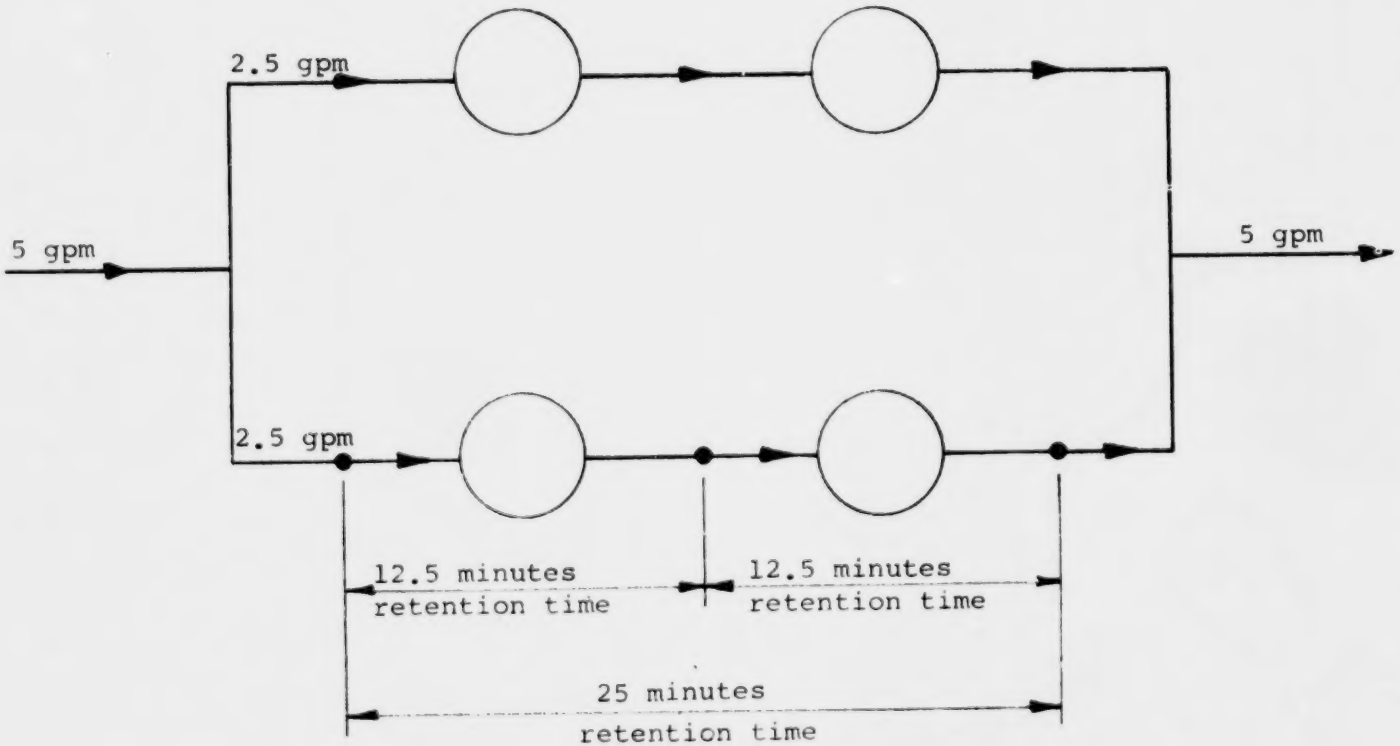
TABLE 6

CARBON COLUMN COMPARISON

PILOT AND VESSEL

	PILOT COLUMNS	VESSEL COLUMNS
DIAMETER (IN.)	5	14
CARBON HEIGHT (FT.)	3	4
CARBON VOL. (GALS.)	3.06	30.9
CARBON VOL. (FT^3)	0.409	4.27
FLOW RATE (GPM)	0.25	2.5
SUPERFICIAL VELOCITY (GPM/FT^2)	1.84	2.43
CARBON CONTACT TIME (MIN.)	12.2	12.4
CARBON	CALGON FILTRASORB 300 (8x30)	CALGON FILTRASORB 300 (8x30)

FIGURE 8
SHIPBOARD CARBON COLUMN ARRANGEMENT
AND RETENTION TIMES



time for each column is 12.5 minutes. The BOD_5 removals obtained in the pilot columns can also be expected from the vessel columns if the following parameters are identical for the two columns: type of carbon, carbon contact time, superficial velocity, and carbon depth. As indicated in Table 6, type of carbon and contact time are identical, superficial velocities are close to each other, and the lower velocity in the pilot columns is compensated for by the smaller depth. Hence the results obtained are one-to-one applicable to the vessel columns. This was confirmed by land-based tests on the full scale vessel columns when the full scale ship system was tested prior to shipment. The results of those tests are listed in Table 7. The data are for two columns in parallel, so that the results apply to a single column for each 2.5 gpm stream. Approximately 1,000 gallons of sewage were processed through the full scale ship system for each of these runs, and sampling and analysis procedures were the same as those described above.

Disinfection

A limited number of tests and analyses were performed to determine the disinfection obtained by chlorination before and after carbon column treatment. The disinfectant employed was household laundry bleach (5.25% sodium hypochlorite) diluted and metered to provide a dosage of 15 mg/l of available chlorine. A hypochlorite was selected as the disinfectant because the U. S. Coast Guard had indicated that they would not approve the use of a gas chlorinator aboard ship, for safety reasons. Of the two hypochlorites (sodium and calcium), preference was given to sodium because it was more readily available, and even though the concentrations of available chlorine are less with bleach than with calcium hypochlorite, the dosages required for 5,000 gpd do not lead to excessive amounts of bleach. The 15 mg/l dosage was selected simply because this is a value recommended in the literature for postchlorination of effluent from secondary treatment plants.

The results are summarized in Table 8. For the first three runs the centrifuge effluent was chlorinated with a dosage of 15 mg/l of available chlorine and a retention time of 15 minutes. This was sufficient to reduce the confirmed total coliform count to less than 14 MPN/100 ml. Examination of the effluent from carbon columns showed,

TABLE 7

SUMMARY OF PERFORMANCE
LAND BASED TESTS ON SHIP SYSTEM
FRESH DOMESTIC SEWAGE
WITH NO CHEMICAL ADDITIVES
AT A FLOW RATE OF 5 GALLONS PER MINUTE

RUN NO.	SUSPENDED SOLIDS				BOD_5			
	F	SU	CE	CCE	F	SU	CE	CCE
13	220	176	36	24	240	180	60	34
14	322	392	40	24	310	420	140	44
15	214	420	62	28	180	160	80	38

TABLE 8

SUMMARY OF DISINFECTION TESTS
LAND BASED TESTS ON PROTOTYPE AND SHIP SYSTEMS

RUN NO.	CENTRIFUGE EFFLUENT	CHLORINATED CENTRIFUGE EFFLUENT	CARBON COLUMN EFFLUENT	CHLORINATED CARBON COLUMN EFFLUENT	CHLORINE RESIDUAL Mg/l
10	1,600	(1) 141	33	-	-
11	1,600	(1) 5	348	-	-
12	16,000	(1) 141 (P)	1,609 (P)	-	-
13	2,400,000	(2) 172 (P)	1,600	(3) 22 (P)	1.0
		(2) 14 (C)		(3) 0 (C)	

NOTES All values in MPN/100 ml
(P) means presumptive
(C) means confirmed

(1) After 15 minutes at 15 mg/l dosage
(2) After 15 minutes at 20 mg/l dosage
(3) After 5 minutes at 15 mg/l dosage

however, that recontamination of the wastewater occurred during passage through the columns. Hence, both pre and post chlorination were used for the fourth run, in which a single column was used. Prechlorination was at a dosage of 20 mg/l of available chlorine with a retention time of 15 minutes, and postchlorination was at a dosage of 15 mg/l of available chlorine with a retention time of 5 minutes. This combination reduced the confirmed total coliform count in the final postchlorinated effluent to zero.

Sludge Density

Since the weight density of the sludge resulting from suspended solids separation is a consideration in sizing the solids holding tank, samples of the vibro-separator screen overflow and the centrifuge solids discharge were analyzed for sludge concentrations. The results are listed in Table 9. The density of the screen overflows varied from approximately 6 to 12% by weight, and the centrifuge discharge from 1.9 to 11.6%. For fresh aerobic sewage (English Village), the variation for the centrifuge discharge density was 4.9 to 11.6%. For a combination of the two types of solids collected in the same tank, it appears safe to use a minimum density of 5%. An average of about 8 to 9% appears to be reasonable.

The significance of sludge density can be determined from Figures 9 and 10. Figure 9 is a plot of dry solids present in wastewater for various flows and suspended solids concentrations. For a concentration of 500 mg/l and a flow of 5,000 gpd, for example, the total weight of dry solids is 20.8 pounds per day. From Figure 10, for this weight the volume of sludge produced is 50 gpd for a 5% sludge and 27.7 gpd for a 9% sludge. The storage volume which must be provided by the solids holding tank is determined by these values. The solids tank provided for the shipboard system (400 gallons) would be adequate for a storage period of about two weeks with the 9% sludge, but not with the 5% sludge.

Summary of Land-Based Tests on Prototype and Ship Systems

The results of the prototype system tests, confirmed by land-based tests on the full scale ship system, showed that, in treating fresh domestic sewage (with suspended

TABLE 9

PROTOTYPE SYSTEM
SLUDGE DENSITIES

RUN NUMBER	SOURCE	SCREEN OVERFLOW	CENTRIFUGE DISCHARGE
3. to 7.	Hatfield	8.58 to 10.32	6.02 to 9.9
8. to 14.	Hatfield	6.12	1.91 to 7.55
16. to 20.	Ft. Washington	9.08	2.5
21.	Ft. Washington	8.36	4.03
22.	Ft. Washington	11.99	5.44
23.	Ft. Washington	8.20	7.78
24.	Ft. Washington	-	5.65
27.	English Village	-	11.6
28.	English Village	-	4.9

NOTES

All Values in Weight Per Cent

For Identification of Run Numbers, See Appendix A-2

FIGURE 9
RELATION BETWEEN DRY SOLIDS WEIGHT,
DAILY FLOW, AND SUSPENDED
SOLIDS CONCENTRATIONS

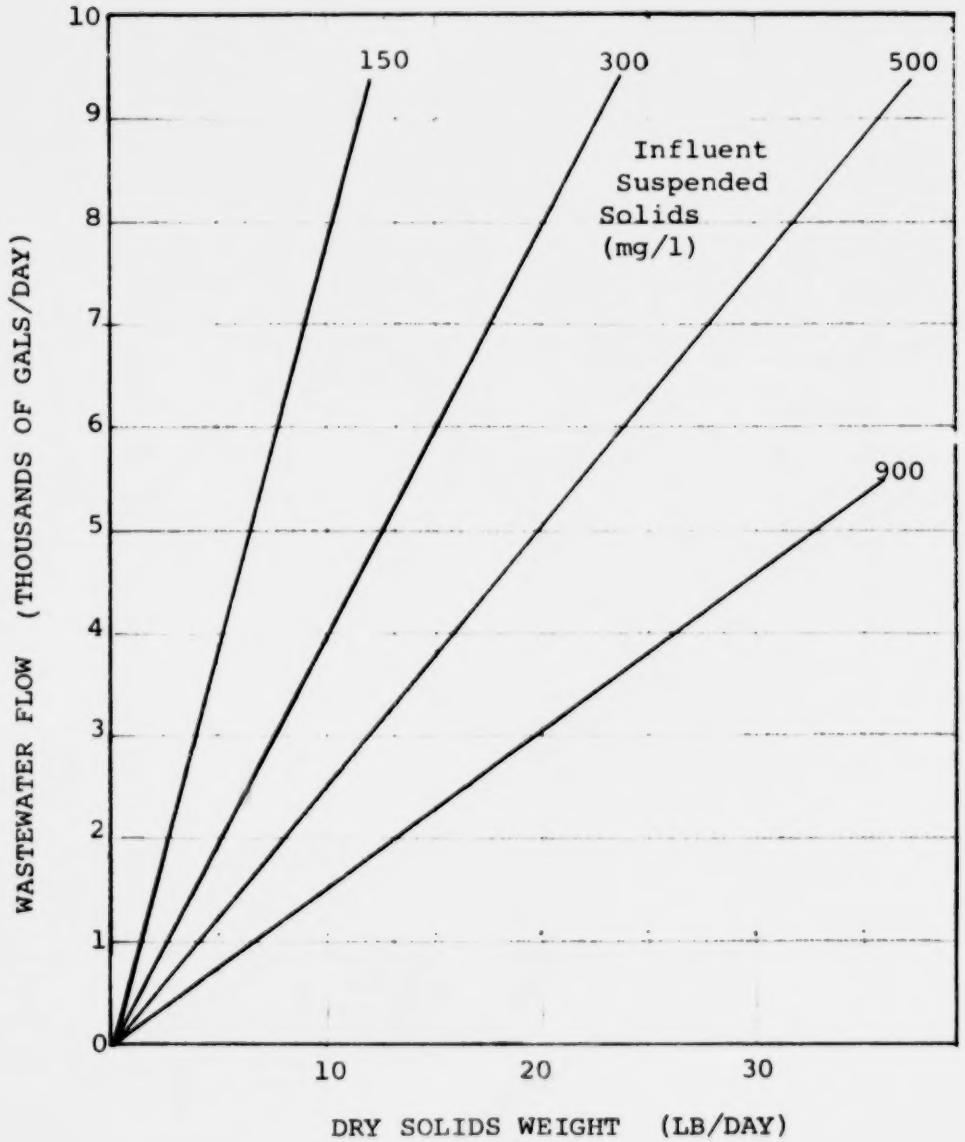
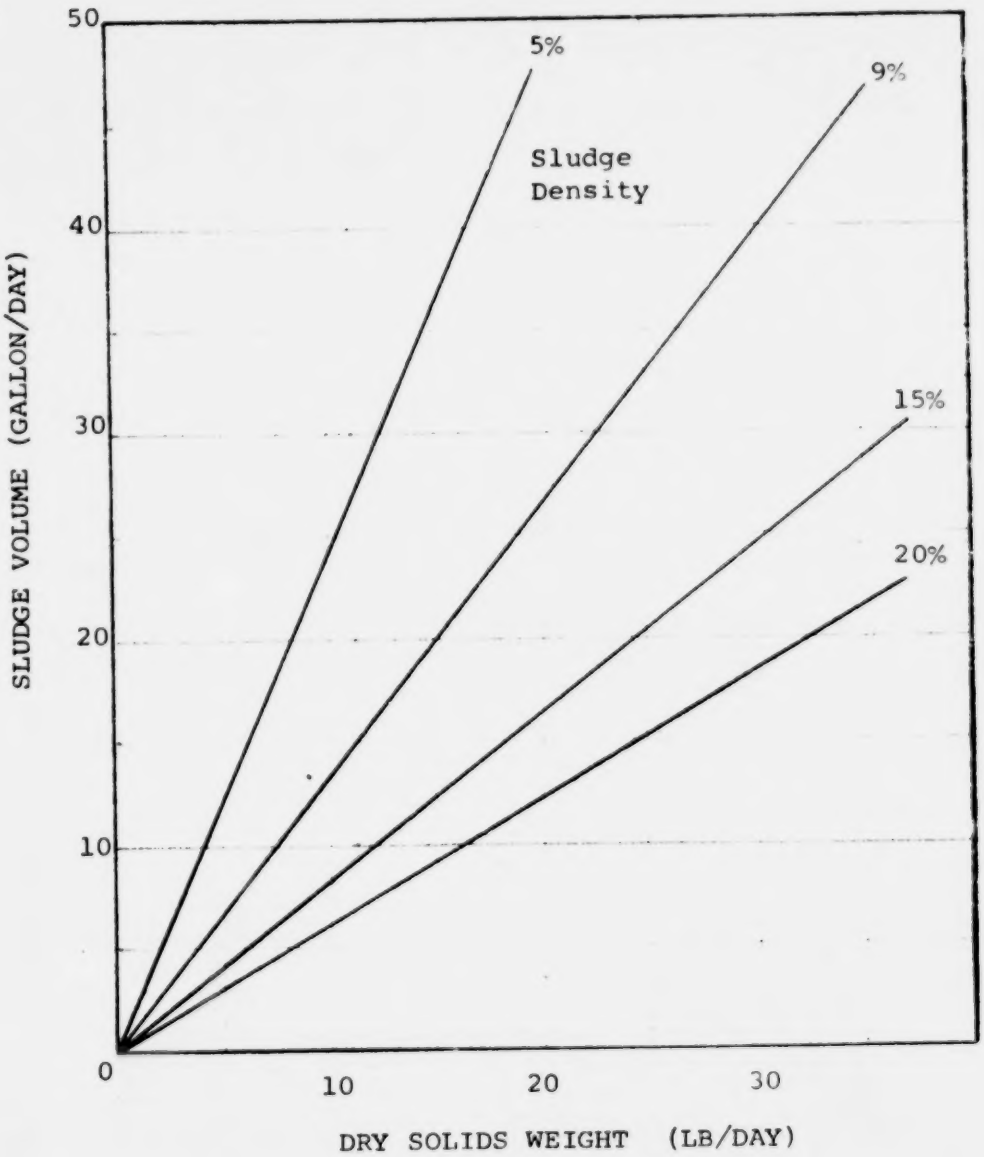


FIGURE 10
RELATION BETWEEN SLUDGE VOLUME,
SLUDGE DENSITY, AND DRY SOLIDS WEIGHT



solids varying from 130 to 480 mg/l and BOD_5 varying from 76 to 420 mg/l), the system, for a flow rate of 5 gpm and without any chemical pretreatment of the sewage, consistently reduced the influent suspended solids and BOD_5 to values less than 50 mg/l. Percentagewise, on an average basis, this represented a suspended solids reduction of 95% and a BOD_5 reduction of 82%. Chlorination at dosages of 15 and 20 mg/l before and after carbon column treatment reduced the total coliform count in the effluent to values approaching zero. Based on very limited data, there was no apparent difference in performance between sewage in fresh water and sewage in sea water.

Hence, the prototype system met the design goals of effluent suspended solids and BOD_5 less than 50 mg/l and a total coliform count less than 240 MPN/100 ml.

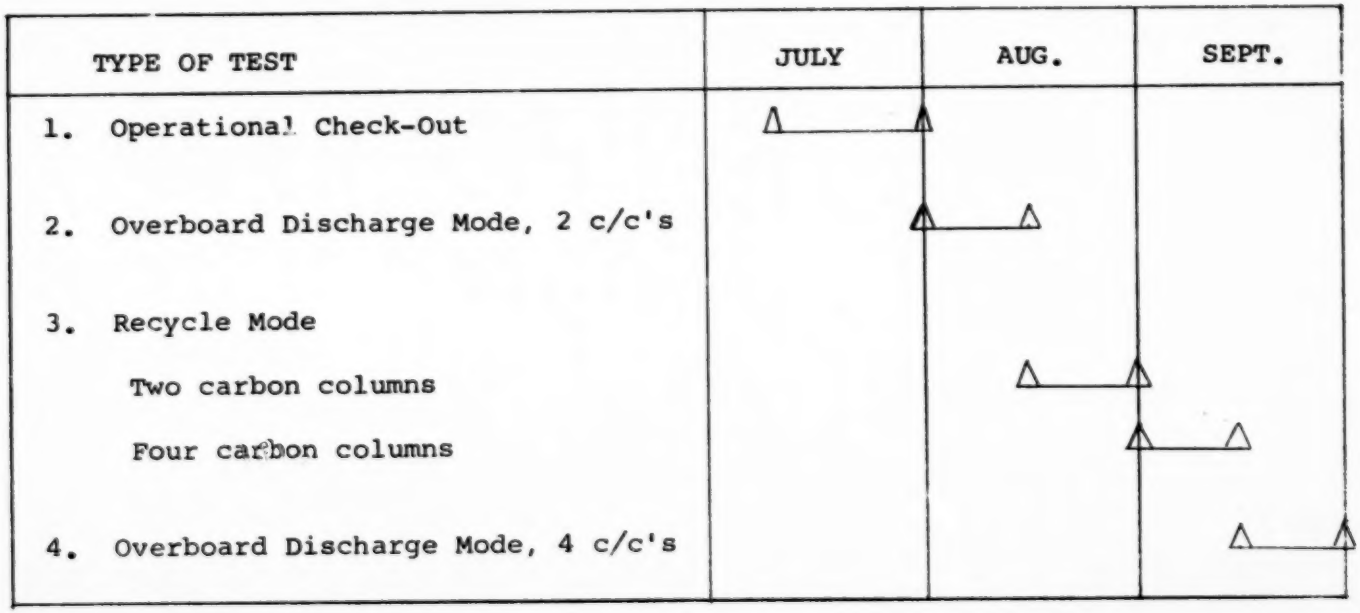
Ship System Tests and Performance

Installation of the shipboard system aboard THE DELAWARE was completed early in July 1972, and operational check-out and crew training commenced on July 11. After promulgation of the Environmental Protection Agency's "No Discharge" standard in June 1972, it was decided to limit the tests of the system in a "flow-through" overboard discharge mode to a minimum number believed adequate to confirm the results of the land based tests, and to emphasize tests of the system in a "no-discharge" recycle mode. The ship system test schedule is shown in Figure 11. Upon completion of the check-out tests in both the overboard discharge and recycle modes, performance data were first obtained with the system operating in the "flow through" mode, using Delaware Bay sea water for flushing purposes, with only two of the four carbon columns operating. Performance data were then obtained for recycle mode testing, first with two and later with four carbon columns, using recycled fresh water for flushing. The program was completed at the end of September with overboard discharge tests employing four carbon columns.

Two-column tests were chosen for the early tests because the land-based tests on the full scale carbon columns showed that the performance goals of suspended solids

FIGURE 11

SHIP SYSTEM TEST SCHEDULE



and BOD_5 less than 50 mg/l could be met with only two columns arranged in parallel (see Table 7), and since an additional two columns were available, it would always be possible to bring these into service if only two columns proved to be inadequate.

A list of all shipboard test runs in given in Table 10, which presents the date of each test run, the operational mode, the type of flush water used, the number of passengers (both the total for the day and the number aboard during the test period), and the wastewater flow (total for the day and the test volume). The total flow values in parentheses are estimates, obtained by multiplying the total number of passengers by the ratio of test flow gallons to test period passengers. For three of the runs (No. 10, 14, and 18), total flows for the day were measured. The test periods and testing procedures are described later in this section.

Table 10 shows that the total flow increased from 3,000 gpd on July 11 to a peak of 6,000 gpd on July 25, and for the month of August varied between 4,000 and 6,000 gpd. In September the flow dropped significantly, varying from 3,000 gpd at the beginning of the month to 300 gpd at the end.

Operational Check-Out Tests

Operational check-out tests (the first six test runs) were conducted in both the overboard discharge and recycle modes in order to establish that all components of the system operated as designed. The test procedure was as follows:

1. The diesel-powered a.c. generator was turned on to provide power to the system.

2. The fresh water feed valve to the system was opened, supplying boiler feed water to the backwash pump and to the fresh water feed pump.

3. The fresh water feed pump was turned on, providing water under pressure to operate four valves on the centrifuge and to flush out the centrifuge during a desludge cycle.

TABLE 10

LIST OF SHIPBOARD TEST RUNS,
PASSENGER LOADINGS, AND TEST FLOWS

RUN NO.	DATE 1972	OPERA-TIONAL MODE	TYPE FLUSH WATER	PASSENGERS		FLOW (GALS)		NO. OF CARBON COLS.	DATA TAKEN
				TOTAL	TEST	TOTAL	TEST		
1	7/11	O/B	Sea	1672	237	(3000)	425	2	No
2	7/13	O/B	Sea	2221	1052	(4400)	2103		
3	7/20	O/B	Sea	2398	257	(4700)	510		
4	7/24	O/B	Sea	2417	849	(4600)	1600		
5	7/25	O/B	Sea	3104	541	(6000)	1030		
6	7/31	Recycle	Fresh	2086	631	(4100)	1228		No
7	8/3	Recycle	Fresh	2585	1096	(4700)	2013		Yes
8	8/8	O/B	Sea	2710	525	(5200)	1003		No
9	8/15	O/B	Sea	2755	520	(5400)	1040		No
10	8/17	Recycle	Fresh	3076	1527	5970	3184	2	Yes
11	8/23	Recycle	Fresh	2933	237	(5800)	470	2	No
12	8/24	Recycle	Fresh	2735	334	(5500)	730	4	Yes
13	8/25	Recycle	Fresh	2479	849	(4500)	1540	2	Yes
14	8/26	Recycle	Fresh	3034	3034	5555	5555		No
15	8/29	O/B	Sea	2271	191	(4300)	325		Yes
16	8/30	Recycle	Fresh	2556	829	(4200)	-		Yes
17	8/31	Recycle	Fresh	2626	849	(4300)	-		Yes
18	9/3	O/B	Sea	2093	2093	3440	3440		No
19	9/6	O/B	Sea	1167	76	(1700)	110		No
20	9/7	O/B	Sea	1143	260	(1700)	430	2	Yes

TABLE 10 (Continued)
LIST OF SHIPBOARD TEST RUNS,
PASSENGER LOADINGS, AND TEST FLOWS

RUN NO.	DATE 1972	OPERATIONAL MODE	TYPE FLUSH WATER	PASSENGERS		FLOW (GALS)		NO. OF CARBON COLS.	DATA TAKEN
				TOTAL	TEST	TOTAL	TEST		
21	9/8	Recycle	Fresh	1379	570	(2100)	870	4	Yes
22	9/9	Recycle	Fresh	1388	-	(2100)	-		
23	9/10	Recycle	Fresh	1929	-	(2900)	-		
24	9/11	Recycle	Fresh	1113	924	(1300)	1065		
25	9/12	Recycle	Fresh	951	846	(900)	819		
26	9/13	Recycle	Fresh	911	789	(900)	889		
27	9/14	Recycle	Fresh	1039	-	(900)	-		
28	9/15	Recycle	Fresh	1251	876	(1100)	800		
29	9/16	Recycle	Fresh	1863	-	(1700)	-		
30	9/17	Recycle	Fresh	2220	-	(2000)	-		
31	9/18	Recycle	Fresh	1175	1047	(1400)	1259		
32	9/19	Recycle	Fresh	981	552	(800)	-		
33	9/20	Recycle	Fresh	1115	1026	(900)	850		
34	9/21	Recycle	Fresh	557	487	(500)	400		Yes
35	9/22	O/B	Fresh	819	644	(700)	500		No
36	9/23	Recycle	Fresh	1597	438	(1000)	-		Yes
37	9/24	Recycle	Fresh	1416	420	(900)	-		Yes
38	9/25	Recycle	Fresh	609	247	(300)	122		Yes
39	9/26	Recycle	Fresh	479	250	(300)	159		Yes
40	9/27	O/B	Sea	655	512	(400)	347	4	Yes

TABLE 10 (Continued)
LIST OF SHIPBOARD TEST RUNS,
PASSENGER LOADINGS, AND TEST FLOWS

RUN NO.	DATE 1972	OPERATIONAL MODE	TYPE FLUSH WATER	PASSENGERS		FLOW (GALS)		NO. OF CARBON COLS.	DATA TAKEN
				TOTAL	TEST	TOTAL	TEST		
41	9/28	O/B	Sea	484	247	(300)	170	4	Yes
42	9/29	O/B	Sea	637	286	(300)	140		
43	9/30	O/B	Sea	709	376	(600)	311		
44	10/1	O/B	Sea	-	-	-	263	4	Yes

NOTE: Quantities in parentheses are estimates.

4. During recycle tests, the effluent pump was turned on to provide water from the recirculation tank to the toilets for flushing.

5. The centrifuge was turned on. After a 2.5 minute interval, the time required for the centrifuge to come to full operating speed, the vibrating screen turned on automatically.

6. The wastewater inlet valve to the sanitation system was opened, and the emergency overboard by-pass valve was closed.

7. Thereafter the system operated automatically, the level controls in the various tanks turning on and off the process pumps and chlorine metering pumps as required.

8. During the maintenance shift, after the vessel was docked for the night, the carbon columns were backwashed for ten minutes with boiler feed water pumped through the columns by the backwash pump. Except during one later stage of the test program, when the carbon columns were backwashed overboard, the backwash water was sent to the collection tank; and after completion of the backwash cycle, the backwash water was re-processed through the system and the treated backwash water was either discharged overboard or pumped to the recirculation tank.

9. At periodic intervals the sludge in the solids holding tank was pumped to a sewage tank truck brought aboard the vessel and hauled away for land disposal.

Although no samples were taken for analysis during the first six runs, grab samples were taken for visual examination. In addition, periodic observations were made during the day of the contents of the various tanks in the system. Chlorine residual readings were also taken on samples withdrawn from the prechlorination and postchlorination tanks. The results were consistently good and apparently comparable to the land-based test results. The effluent was clear in color, contained no visible particles, and exhibited a chlorine residual. From these preliminary results, it was concluded that

the system was operating properly, and the taking of samples for analysis was begun.

Maintenance and Operational Experience

Only minor component difficulties were encountered throughout the land-based testing and the three-month shipboard program. Two level gages shorted out, one caused by an overflow of the collection tank (discussed below) while operating in an inadvertent unsealed tank condition, and the other due to an unexplained liquid penetration of the level gage seal. Late in the test program the rubber stator in the feed pump showed signs of excessive wear and was replaced. It is believed that this was due to a combination of the temperature of the boiler feed water in the pump (in excess of 100° F) and the fact that the pump was run continuously with no discharge for approximately 16 hours a day.

Only two operational difficulties occurred. During the peak passenger period (latter part of July to mid-August) the rate of flow into the collection tank during peak flow periods at times produced a volume of water which exceeded the storage capacity of the tank, and it was necessary to by-pass the incoming flow overboard for a short period. During overboard discharge mode operation, it was found that this condition was aggravated by toilet flushing valves stuck in the open position. The valves tend to become stuck when the vessel's sanitary pump draws sand from the bottom of the bay when the vessel is loading or unloading at Cape May and Lewes. However, the tank flooding condition also occurred during recycle mode tests. As mentioned earlier, the collection tank was sized for 600 gallons, based on a 5,000 gpd system size. As indicated in Table 10, however, the flow during the peak passenger period was 6,000 gpd. For Run No. 10, a total flow of 5,970 gpd was measured, and for Run No. 5, a total flow of 6,000 gpd was estimated. Flows in excess of 5,000 gpd were also either measured or estimated for Runs 8, 11, 12, and 14. For a 6,000 gpd system the collection tank is slightly undersized. A volume of 800 gallons rather than 600 gallons would have eliminated the problem. For the system as actually installed on the ferry, the problem can be solved simply by additional pumps

which increase the flow-through rate in the system when the liquid level in the collection tank becomes too high. The increased flow rate for short periods of time would not seriously affect the overall performance of the system.

The other operational difficulty encountered was the flooding of the solids holding tank on three occasions. This happened twice when the fresh water feed valve from the boiler feed tank to the sanitation system was inadvertently left open during the ferry maintenance shift, at the same time that the valve to the fresh water feed pump and the valves on the centrifuge were left open, with the centrifuge not operating. High pressure surges during the filling of the boiler water feed tank caused water to leak through all valves into the solids holding tank. The solids tank was also flooded once when the pressure setting on the centrifuge feed valve was accidentally set at 80 psi rather than 40 psi.

Apart from these problems, the system operated as designed, with a minimum of down-time.

Test, Sampling and Analysis Procedures

Three different test periods were used when samples were taken for analysis. Sample pick-up at Lewes, Delaware, was governed by arrival times of the ferry. The most frequent test periods were for samples collected and composited from 0700 hours until 1230 hours, with pick-up at 1300 hours, or for samples collected and composited between 1100 hours and 1630 hours, with pick-up at 1700 hours. In either case, the test period covered three continuous trips, with a time span of 5.5 hours. On a number of occasions samples were collected and composited from 0700 to 1630 hours, with pick-up at 1700 hours.

Early in the program samples were taken at the following locations: collection tank effluent (vibro-separator underflow), centrifuge effluent, carbon column effluent, and post-chlorinated effluent. Later in the program, in order to minimize sample analysis costs, sampling was confined to vibro-separator underflow and post-chlorinated effluent. For each location grab samples were taken approximately once each hour and composited in one-gallon

plastic containers which were kept on ice. At Lewes these containers were transferred to ice chests and driven to the analysis laboratory, where analyses were immediately started. When the plastic containers were picked up at Lewes, a laboratory representative came aboard the vessel and took a sample for coliform bacteria analysis. The sampling outlet was heated with a torch immediately before withdrawal of the sample. A chlorine residual reading was taken, and then the sample was dechlorinated. All analyses were performed in accordance with approved EPA procedures in "Methods for Chemical Analysis of Water and Wastes."

Results of Overboard Discharge Mode Tests

Performance data were taken for seven overboard discharge mode tests. Early in the program the system was operated with only two carbon columns in service, arranged in parallel, which provided a carbon contact time of 12.5 minutes. At the end of the program, following the recycle mode tests, the system was again operated in the overboard discharge mode, with four carbon columns arranged in parallel-series, which provided a carbon contact time of 25 minutes. For all of the overboard discharge mode tests the toilet flushing water was sea water pumped from Delaware Bay.

The suspended solids and BOD_5 data for these teste are listed in Tables 11 and 12, the former representating the two-column data and the latter the four-column data. Samples were taken of the vibrating screen underflow (SU), the centrifuge effluent (CE), the carbon column effluent (CCE), and the post-chlorination effluent(PCE). The piping arrangement at the influent end of the marine sanitation system was such that it was difficult to take samples of the incoming feed (F). Therefore the suspended solids and BOD_5 levels in the feed were estimated. This was done as follows. For the suspended solids alone, the prototype tests (Table 5) showed that approximately 30% of the suspended solids in the influent were removed by the vibrating screen. It is felt that this same percentage could be applied for estimating purposes to solids in the shipboard wastewater. Hence, the feed suspended solids values were estimated on this basis. The prototype tests also showed that approximately 20% of the BOD_5 in influent wastewater was

TABLE 11

SUMMARY OF PERFORMANCE
SHIPBOARD OVERBOARD DISCHARGE MODE TESTS
SEA WATER FLUSHING
FLOW RATE OF 5 GALLONS PER MINUTE
TWO CARBON COLUMNS

RUN	SUSPENDED SOLIDS					BOD_5				
NO.	F	SU	CE	CCE	PCE	F	SU	CE	CCE	PCE
15(1)	(200)	143	-	25	70	(330)	294	190	*290	33
15(2)		329	236	216	217	(360)	326	218	39	33
20		*80	*148	*112	*154	(230)	210	160	60	60

NOTES

All values in mg/l

F means Feed (Values estimated)
SU means Screen Underflow
CE means Centrifuge Effluent
CCE means Carbon Column Effluent
PCE means Post-chlorinated Effluent

(1) Samples analyzed by E. H. Richardson Associates, Inc.
(2) Samples analyzed by EPA

* Erratic Test Data

TABLE 12

SUMMARY OF PERFORMANCE
SHIPBOARD OVERBOARD DISCHARGE MODE TESTS
SEA WATER FLUSHING
FLOW RATE OF 5 GALLONS PER MINUTE
FOUR CARBON COLUMNS

RUN.	SUSPENDED SOLIDS			BOD_5		
NO.	F	SU	PCE	F	SU	PCE
40	(250)	178	45	(230)	210	110
41	(380)	263	60	(440)	390	130
42	(280)	193	18	(960)	860	150
43	(940)	660	43	(570)	510	110
44	(550)	388	40	(330)	300	98

removed by the vibrating screen. For wastewater generated aboard the ferry, however, it is believed that a greater percentage of BOD_5 is in dissolved form, and consequently, for estimating purposes, it was assumed that only 10% of the total incoming BOD_5 would be removed by the screen. The estimated feed values are shown in parentheses.

Table 11 shows that the two-column shipboard tests confirmed the BOD_5 removal performance of the prototype system. Two sets of data are shown for Run No. 15. The test samples were split, half going for analysis to E. H. Richardson Associates, Inc., Dover, Delaware (the commercial laboratory which performed all analyses for the shipboard tests), and the other half to EPA's National Environmental Research Center in Edison, New Jersey. Except for a disagreement on the BOD_5 in the carbon column effluent (290 mg/l from the Richardson analyses and 39 mg/l from the EPA analyses), the data are in reasonable agreement. It is believed that the Richardson value for CCE is in error, since it would represent an increase in BOD_5 in passing through the carbon columns.

The analytical results for suspended solids from these tests are questionable. For Run No. 15 the two laboratories disagree both regarding magnitude and pattern of removal through the sanitation system. In addition, the suspended solids pattern for Run No. 20 is erratic. Hence, the suspended solids data from these tests are inconclusive.

The results of Runs No. 40 through 44 (Table 12), on the other hand, show a consistent pattern for both suspended solids and BOD_5. The suspended solids in the post-chlorinated effluent range from 18 to 60 mg/l, with all values except one below 50 mg/l. Percent reduction based on estimated suspended solids in the feed (250 to 940 mg/l) was 90%. These results are slightly lower than those obtained with the prototype system.

For Runs 40 through 44 the BOD_5 values in the post-chlorinated effluent vary over a very narrow range (98 to 150 mg/l, with an average of 120 mg/l) for estimated influent BOD_5's ranging from 230 to 960 mg/l, with an average of 506 mg/l. On an average basis this represents a BOD_5 reduction of 76%, which is lower than the reduction of 82% obtained with the prototype system. That the system

is capable of reducing the BOD_5 in shipboard wastewater to values less than 50 mg/l was established by the test results shown in Table 11 and some of the early recycle tests discussed later in this report. A number of possible reasons, therefore, suggest themselves for the higher values:

1. The higher BOD values may reflect carbon column exhaustion caused by the preceding recycle mode tests. Of the four carbon columns in service for Runs 40 through 44, the first two had previously been the second set for Runs No. 21 through 34 and had then become the first set for Runs 35 through 44. During the recycle tests these columns were exposed to the higher organic loadings experienced in the recycle tests and to dosages of potassium permanganate and disinfecting chemicals (pine oil in some cases and a commercial toilet cleaner containing hydrochloric acid).

2. The higher BOD's may be the result of inadequate backwashing of the carbon columns. It was noticed that the effluent from the fresher second set of carbon columns was darker than the first set, which is the reverse of what had been observed during previous tests. All four carbon columns are backwashed simultaneously, with the backwash flow being split between each set of columns and then converging at a single connection in the piping system. It is possible that the backwash flow did not split evenly and that a larger percentage of the flow passed through the older columns, causing a build-up of solids in the second set of columns.

For Runs No. 15 and 20 (Table 11) the total and fecal coliform bacteria counts in the effluent were less than 10 MPN/100 ml for a prechlorination dosage of 15 mg/l and a post-chlorination dosage of 20 mg/l, and chlorine residuals varied from 1.0 to 3.0 mg/l. On some of the early test runs, overboard discharge and recycle modes, occasional fecal coliform counts as high as 3,000 MPN/100 ml were recorded. These deviations from the < 10 value followed no pattern and appeared to be caused by carbon fines in the effluent which adsorbed the chlorine. No coliform data were taken for Runs 40 through 44 (Table 12), but measurements taken during the test showed a chlorine residual greater than 1.0 mg/l.

In reviewing the overboard discharge results it should be pointed out that at least 9 days of "flow-through" testing were conducted at the beginning of the shipboard test period during which the effluent was visually checked. The results were consistently good and apparently comparable to the land test results, i.e., essentially no visible particles, clear in color and containing a chlorine residual. Consequently, data for only 7 test runs (2 before recycle testing and 5 after) were obtained. The suspended solids results from these tests are considered to be good. The BOD results before the recycle testing are also good, with the results after the recycle testing higher than previously experienced, as discussed above. The first day results of recycle tests, presented in the following section, are similar to "flow-through" testing and confirm the system capability in this regard.

Results of Recycle Mode Tests

Two-Carbon Column Tests

Recycle mode tests were first run with only two carbon columns in service, arranged in parallel. The flushing water employed was fresh city water, stored in a 1,400 gallon recirculation tank, which after passage through the sanitation system, was recycled back to the tank. Suspended solids and BOD_5 data for these tests are listed in Table 13, COD data in Table 14, and disinfection data in Table 15. Runs 7 and 10 were separate single-day runs, with a fresh tank of water used for each run. Run 12 was the first day of a multi-day run, with Run 13 the second day. For Run 12 four carbon columns were used for 730 gallons of the 2,578 gallons processed that day, while for Run 13 only two columns were employed. The suspended solids data for all of these tests are in excellent agreement. Both sets of data confirm that, in a "flow-through" mode, the system met the design goals, since these one-day runs are comparable to a flow-through case in which the treated water is not reused. The COD data for Run No. 10 (Table 14) essentially confirm the BOD_5 data for that run. Run No. 12 is especially interesting. The incoming suspended solids were high (870 mg/l estimated), and the BOD_5 loading was very high (in excess of 1,000 mg/l), due in part to the use of pine oil in the toilets on that day.

TABLE 13
SUMMARY OF PERFORMANCE
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
TWO CARBON COLUMNS

RUN	SUSPENDED SOLIDS					BOD_5					
NO.	F	SU	CE	CCE	PCE	F	SU	CE	CCE	PCE	
7	-	-	-	-	-	-	-	-	-	44	(1)
10	(170)	118	22	10	6	(230)	210	170	57	69	(1)
12	(870)	613	115	28	18	(1100)	1000	720	160	12	(2), (3)
13	(520)	363	38	8	15	(830)	750	540	370	270	(4)

NOTES

(1) Single day test
(2) Four carbon columns
(3) First day of multi-day test
(4) Second day of multi-day test

TABLE 14

COD DATA FOR SINGLE RUN
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
TWO CARBON COLUMNS

RUN	SUSPENDED SOLIDS					BOD_5				
NO.	F	SU	CE	CCE	PCE	F	SU	CE	CCE	PCE
10	(170)	118	22	10	6	-	630	300	89	66

NOTE

See Table 13, Run No. 10, for corresponding BOD_5 data.

TABLE 15

DISINFECTION DATA
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
TWO CARBON COLUMNS

RUN NO.	COLIFORM IN EFFLUENT MPN/100 ml		CHLORINE RESIDUAL mg/l
	TOTAL	FECAL	
7	47,000	3,300	0
10	< 10	< 10	1.0
12	< 10	< 10	1.0
13	21,000	300	0.5

The system responded well to this high loading.

Run No. 12 is the first day of a two-day recycle test, and Run No. 13 is the second day. The high influent suspended solids and BOD_5 of Run No. 12 were reduced by the system, and the influent values for both parameters were lower on the second day. Influent variations such as these were also exhibited in the "flow-through" tests (see Table 12). The sanitation system reduced the suspended solids, but an increase in BOD_5 occurred in the effluent. In addition, a noticeable ammonia odor was detected in the recycle tank.

The coliform count in the post-chlorinated effluent for these recycle mode tests is shown in Table 15. The high values for Run No. 7 were believed to be caused by carbon fines in the post-chlorination tank which adsorbed some of the chlorine, making it unavailable for disinfection. The reason for the counts in Run No. 13 is unknown. For Runs No. 10 and 12 the counts were less than 10 MPN/100 ml.

Four-Carbon Column Tests

Sustained four-column recycle mode tests of the sanitation system commenced with Run No. 21 and continued through Run No. 39 (see Table 10). For Runs 21 through 25, potassium permanganate was added to the post-chlorination step to determine if chemical oxidation of the effluent would reduce the build-up of BOD_5 encountered during recycling of the treated wastewater. This approach was abandoned for Runs No. 26 through 30, in which the chlorination dosage was increased. For Runs No. 31 through 39 the carbon columns were backwashed overboard instead of back into the system.

Suspended Solids and BOD_5 Reduction

The performance data for Runs 21 through 25, a continuous 5-day recycle test, are summarized in Table 16. Chlorine dosage was 15 mg/l in the prechlorination step and 30 mg/l in the post-chlorination step. The potassium permanganate dosage, also added at the post-chlorination step, was 35 mg/l. Except for Run No. 25, the suspended solids date are consistent with the results of the prototype system tests. Three of the five tests show an increased in suspended solids in passing through the post-chlorination step, due possibly

TABLE 16

SUMMARY OF PERFORMANCE
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
CHLORINATION AND POTASSIUM PERMANGANATE TREATMENT
FOUR CARBON COLUMNS

RUN NO.	SUSPENDED SOLIDS					BOD_5					RECYCLE DAY
	F	SU	CE	CCE	PCE	F	SU	CE	CCE	PCE	
21	(280)	196	156	24	52	(130)	120	100	-	-	1
22	(620)	436	60	54	52	(400)	360	380	110	130	2
23	(220)	152	38	25	60	(460)	410	320	200	220	3
24	(300)	212	60	42	50	(410)	370	160	310	320	4
25	(240)	170	60	72	70	(340)	310	300	220	140	5

NOTES

Prechlorination dosage: 15 mg/l
Post-chlorination dosage: 30 mg/l
Potassium permanganate dosage: 35 mg/l

Values in parentheses are estimates

to a slight build-up of solids in the post-chlorination tank. The BOD_5 values in the effluent continue to increase with each day of recycling, except for an unexplained decrease on the fifth day. The BOD_5 data for Run No. 24 are inconsistent. Either the centrifuge effluent (CE) BOD is too low or the carbon column effluent (CCE) and post-chlorinated effluent (PCE) are too high. It is interesting to note that, even though the final BOD's are high, the system continued to decrease the incoming BOD.

The potassium permanganate, at the dosage employed, had no apparent effect on the BOD_5 levels in the recycled effluent. Hence, because of the corrosiveness of this material and the fact that it discolored the flushing water, its further use was discontinued.

The next series of recycle mode tests was performed with increased chlorine dosage in both the prechlorination and post-chlorination steps. Prechlorination dosage was increased to 40 mg/l and post-chlorination to 200 mg/l. The suspended solids and BOD_5 results for these tests (Runs 26 through 30) are listed in Table 17. The data for the first day of these tests (Run No. 26) confirm the order of magnitude of the flow-through mode results, but for all subsequent days both the suspended solids and BOD_5 results showed a build-up. The solids build-up and ammonia odor led to the termination of this series of tests.

With the increased chlorine dosages of Runs 26 through 30 retained, a series of runs was then made to determine the effects of backwashing the carbon columns overboard rather than back into the system. The results of these runs (31 through 34) are listed in Table 18. For Runs 33 and 34 two sets of data are presented, analyzed by E. H. Richardson Associates, Inc. and EPA's National Environmental Research Center. The EPA values for suspended solids and BOD_5 are consistently lower, but the fact that most of the values are in reasonable agreement established the credibility of the analytical procedures employed throughout the test program. Again, the suspended solids data confirm the order of magnitude of the prototype system tests. The BOD_5 data show no substantial difference from values obtained in the previous recycle mode runs, except that the high values for Run No. 31, the first day of this series with a fresh tank of water, indicate that the carbon columns may be ap-

TABLE 17

SUMMARY OF PERFORMANCE
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
INCREASED CHLORINE DOSAGE
FOUR CARBON COLUMNS

RUN	SUSPENDED SOLIDS					BOD_5					RECYCLE
NO.	F	SU	CE	CCE	PCE	F	SU	CE	CCE	PCE	DAY
26	(220)	152	94	36	40	(360)	320	340	100	64	1
27	(340)	240	182	104	82	(720)	650	450	240	250	2
28	(410)	288	228	105	95	(620)	560	500	320	320	3
29	(1150)	806	342	86	104	(840)	760	530	280	260	4
30	-	93	183	78	73	(690)	620	540	410	410	5

NOTE

Prechlorination dosage: 40 mg/l
Post-chlorination dosage: 200 mg/l

Values in parentheses are estimates

TABLE 18

SUMMARY OF PERFORMANCE
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
CARBON COLUMNS BACKWASHED OVERBOARD
FOUR CARBON COLUMNS

RUN NO.	SUSPENDED SOLIDS			BOD_5			RECYCLE DAY
	F	SU	PCE	F	SU	PCE	
31	(200)	138	13	(430)	390	250	1
32	(720)	505	53	(760)	680	320	2
33*	(290)	206	55	(650)	590	320	3
33*÷	(270)	190	45	(580)	521	233	3
34*	(480)	333	75	(770)	690	330	4
34**	(360)	252	31	(410)	372	307	4

NOTES

* Samples analyzed by E. H. Richardson Associates, Inc.

** Samples analyzed by EPA

Values in parentheses are estimates

proaching exhaustion. It is significant, however, that the carbon columns are still reducing the incoming BOD_5. EPA grab sample data corresponding to Runs 33 and 34 are presented in Table 19, and show that there is no difference between the grab and composite sample data.

For the final series of recycle mode tests (Runs 35 through 39), the carbon was replaced in two of the four columns. The fresh columns became the second set in the parallel-series arrangement. Low wastewater flows on the ferry during this period hampered the taking of meaningful data. The suspended solids and BOD_5 data are listed in Table 20. Data were not available for the first day of the series (Run No. 35) because of the time consumed in changing the carbon, but the results for the second day (Run No. 36) indicate that the first day values would have duplicated the results of the prototype system tests. Data from subsequent days show the usual build-up in BOD_5. The color of the recycle water, which was clear at the beginning, became milky in appearance and then became gray by the end of the recycle series.

Nitrogen in the System

As mentioned above, by the second day of the recycle mode tests, a noticeable ammonia odor appeared in the recycled wastewater. Analyses of the post-chlorinated effluent were performed to determine both the ammonia and organic nitrogen levels present, and the results are listed in Table 21. Generally the ammonia nitrogen values are an order of magnitude higher than the values in raw domestic sewage (see Appendix A4). The temperature of 90°F is an estimate based on the fact that the temperature in the hold of the vessel where the sanitation system was located varied from about 110°F during July and August to about 95°F during the latter part of September.

The nitrogen levels show no consistent pattern. Runs 28 through 30, for example, represent the third through fifth days of a five-day series of tests. The ammonia nitrogen increases steadily, but the organic nitrogen is not consistent. These were tests at the increased chlorination levels discussed above. Runs 31 through 34, on the other hand, show a consistently decreasing ammonia nitrogen level, with scatter in the organic nitrogen. These were tests at the increased chlorination levels with the carbon columns

TABLE 19

EPA GRAB SAMPLE DATA
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
CARBON COLUMNS BACKWASHED OVERBOARD
FOUR CARBON COLUMNS

DATE		SUSPENDED SOLIDS					BOD_5				
1972	TIME	F	SU	CE	CCE	PCE	F	SU	CE	CCE	PCE
9/20	1 PM	(160)	114	77	-	19	(660)	593	486	-	277
9/20	3 PM	(330)	232	65	-	54	(700)	632	482	-	294
9/21	11 AM	(270)	188.	184	-	60	(410)	372	355	-	346
9/21	1 PM	(320)	221	177	-	41	(460)	413	366	-	239
9/21	3 PM	-	-	250	-	85	(530)	479	497	-	333

NOTES

9/20 samples correspond to Run No. 33 in Table 18
9/21 samples correspond to Run No. 34 in Table 18

Values in parentheses are estimates

TABLE 20

SUMMARY OF PERFORMANCE
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
EFFECTS OF CHANGING TWO OF FOUR CARBON COLUMNS

RUN NO.	SUSPENDED SOLIDS			BOD_5			RECYCLE
	F	SU	PCE	F	SU	PCE	DAY
35	-	-	-	-	-	-	1
36	(240)	168	56	(400)	360	120	2
37	(210)	148	84	(490)	440	250	3
38	(350)	246	62	(830)	750	350	4

NOTE

Values in parentheses are estimates

TABLE 21

SHIPBOARD RECYCLE MODE TESTS
FLOW RATE OF 5 GALLONS PER MINUTE
NITROGEN LEVELS IN POST-CHLORINATED EFFLUENT

RUN NO.	NH_3-N	ORGANIC N	pH	TEMP °F
28	200	140	8.9	~ 90
29	360	370	9.0	
30	460	170	8.7	
31	340	220	8.7	
32	230	190	8.7	
33	200	250	8.9	
34	50	50	8.9	
35	-	-	-	
36	145	5	9.0	
37	266	-	8.7	
38	100	-	8.7	~ 90

NOTE

All nitrogen values in mg/l

backwashed overboard. Since the only difference between the tests of Runs 28-30 and 31-34 are the overboard backwash of the carbon columns and a somewhat decreased passenger loading for the latter tests, the steadily decreasing ammonia levels might be attributed to the overboard backwash of the columns. However, the carbon columns were also backwashed overboard for Runs 36-38, and in addition fresh carbon was added to two of the four columns, yet these tests showed scatter in the ammonia nitrogen levels. EPA analyses for the grab samples taken on 9/20 and 9/21/72 (Runs 33 and 34) show ammonia nitrogen levels of 270 mg/l, which are higher than the values in Table 21.

Disinfection

The coliform count in the post-chlorinated effluent for the four-column recycle mode tests are listed in Table 22. Except for an occasional deviation, including one caused by lack of prechlorination, the total and fecal coliform counts are less than 10 MPN/100 ml. Chlorine residuals are generally 1.0 mg/l.

Summary of Recycle Mode Test Results

From the results obtained in all of the recycle mode tests, the following general conclusions can be drawn:

1. On the first day of the recycling operation, using a fresh tank of water, the suspended solids and BOD_5 loadings in the post-chlorinated effluent are in the 50 mg/l range. This substantiates the flow-through results for both the prototype and shipboard tests, and confirms that the sanitation system, operated in the flow-through mode, met the design objectives of the program. The recycle water is slightly cloudy but clean in appearance.

2. After the first day the BOD_5 of the recycled effluent increases so that by the end of 5 days its value is in the range 200 to 400 mg/l. Suspended solids levels, however, are generally low.

3. By the second day the recycled wastewater exhibits a noticeable ammonia odor. The ammonia nitrogen levels vary from 50 to more than 300 mg/l. The color of the water

TABLE 22

DISINFECTION DATA
SHIPBOARD RECYCLE MODE TESTS
FLOW RATE AT 5 GALLONS PER MINUTE
FOUR CARBON COLUMNS

RUN NO.	TOTAL COLIFORM	FECAL COLIFORM	CHLORINE RESIDUALS
22	4×10^3	10	1.0
23	80×10^3	800	0
24	10	< 10	1.5
25	10	< 10	2.0
26	10	< 10	1.0
27	1.1×10^6	80×10^3*	0
28	10	< 10	1.0
29	20	< 10	3.0
30	< 10	< 10	1.5
31	-	< 10	2.0
32	-	< 10	1.0
33	-	< 10	1.0
34	-	< 10	1.0
35	-	-	-
36	-	< 10	2.0
37	-	< 10	1.5
38	-	< 10	2.0

NOTES

All values in MPN/100 ml except chlorine residuals

* Post-chlorination only

becomes gray and darker as the number of recycle days increases.

Recommended Recycle Mode Design Changes

As explained earlier, the marine sanitation system demonstrated on this program was designed as a "flow-through" system which provides a high degree of treatment. An investigation of recycling of the effluent showed that, in order to make the system an effective recycle system certain design changes would be required. The following are recommended:

1. The ammonia in the system can be reduced by air stripping. This can be accomplished by agitating and aerating the recycle wastewater in the storage tank. This technique is most efficient at high pH and temperature values, and consequently pH monitoring and control would be required. The elevated temperature in the hold of the vessel may be sufficient without additional heating. Breakpoint chlorination may also be employed for ammonia removal.

2. BOD_5 in the recycled wastewater can be reduced by chemical oxidation following carbon column treatment. Sodium hypochlorite is not suitable, since the concentrations of available chlorine are not sufficiently high. Chlorine can either be generated aboard using a brine solution as a source or a chemical like calcium hypochlorite (with 70% available chlorine) may be employed. Chlorine dosages required would probably be of the order of magnitude of thosands of milligrams per liter. In either case the design must take into consideration the handling and disposal of the oxidation products, corrosive effects, etc.

Solids Collection and Disposal

Except for the flooding of the solids holding tank on three occasions (discussed earlier in this report), no problems were encountered with the holding of solids in a tank vented to weather and periodic pump-out to a sewage tank truck brought aboard the vessel during the maintenance shift. The tank was emptied approximately once every two weeks except during the latter part of the problem, when the program director insisted on weekly pump-out, following

the tank flooding incidents, in order to ensure no interruptions to the test program. Actually, the weekly pump-outs were unnecessary since by this time operating personnel had been indoctrinated about the necessity for closing the valves which led to the flooding problems.

The sludge pumped easily to the tank truck, and only on two occasions was it necessary to dismantle the solids pump because solids were stuck in the impeller. On one occasion this was caused by the presence of a comb, which collected paper towels about itself.

No sludge density data were obtained during the shipboard tests. From observation, the sludge did not differ in appearance from the sludge collected during the land-based tests. The 400 gallon solids holding tank proved to be entirely adequate.

As mentioned earlier in this report, the solids were ultimately disposed of at a sanitary landfill.

Initial and Operating Costs

As part of the program, initial and operating cost data were obtained. These are presented in Table 23. Initial costs were $66,000, consisting of $40,000 for system hardware and $26,000 for system installation, including ship modifications. Operating costs were $200/month for the months of July through September. Estimated operating costs for the remaining months is $85/month. No additional manpower operating costs were required, since operation and maintenance of the system were handled by regular crews, in addition to their normal duties.

TABLE 23

INITIAL AND OPERATING COSTS

INITIAL COSTS

System hardware costs	$40,000
Installation costs (including vessel modifications)	26,000
Total Initial Costs	$66,000

OPERATING COSTS (July through September)

ITEM	QUANTITIES/MONTH	COSTS/MONTH
Activated Carbon	120 lb.	$40
Disinfectant	120 gal.	60
Fuel Oil	140 gal.	20
Sludge Removal	2	80
	TOTAL	$200

ESTIMATED OPERATING COSTS (October through June)

ITEM	QUANTITIES/MONTH	COSTS/MONTH
Activated Carbon	43 lbs.	$13
Disinfectant	60 gal.	12
Fuel Oil	140 gal.	20
Sludge Removal	1	40
	TOTAL	$85

ADDITIONAL MANPOWER COSTS: NONE

SECTION VII

EVALUATION OF CAPABILITIES AND APPLICATIONS

The results of the tests performed on the Marland marine sanitation system have shown that a "flow-through" system capable of providing a high degree of secondary treatment has been demonstrated, and the results of the recycle mode test have indicated the design additions which will be required to upgrade the system to a true recycle system for no-discharge applications. Moreover, the modular design of the system makes it capable of meeting the EPA standards promulgated on June 23, 1972. Referring to the process flow diagram shown in Figure 1, the EPA's "primary treatment" standard for existing vessels (no visible floating solids and a coliform bacteria count in the effluent less than 1,000 MPN/100 ml) can be met by eliminating the carbon columns and centrifuge from the flow-through system and discharging the pre-chlorinated wastewater directly overboard. This would require a higher chlorine dosage, but since the only suspended solids in the effluent are those which have passed through a fine screen (64 to 105 mesh), the chlorination would be effective. A higher degree of treatment would be obtained by retaining the centrifuge but still eliminating the carbon columns. Varying degrees of higher treatment can be obtained by adding varying numbers of carbon columns to the system. The highest treatment - a true no-discharge recycle system - can be obtained by the design additions described earlier in this report.

Although this demonstration grant was conducted on a large ferry, requiring a 5,000 gpd system, the system can be sized to handle flows from 500 to 20,000 gpd, and possibly higher. In its various sizes it is applicable to tug boats, freighters, tankers, passenger liners, offshore drilling rigs, military vessels, etc. For example, a 4,000 gpd system designed for a 40-man crew was installed on the tanker S. S. Mobil Arctic and is shown in Figure 12. In contrast to the spread-out arrangement used aboard the Cape May-Lewes Ferry, the entire system was packaged into a space measuring approximately 11 x 7 x 7 feet.

The system can also be used in land applications where tight space is a governing consideration. The system would be expecially applicable to marinas receiving and treating shipboard wastes retained in holding tanks. For this application chemical treatment with coagulants would be desirable prior to centrifuging.

In summary, the physical-chemical nature of the system and its modular design make the system extremely flexible in its applications.

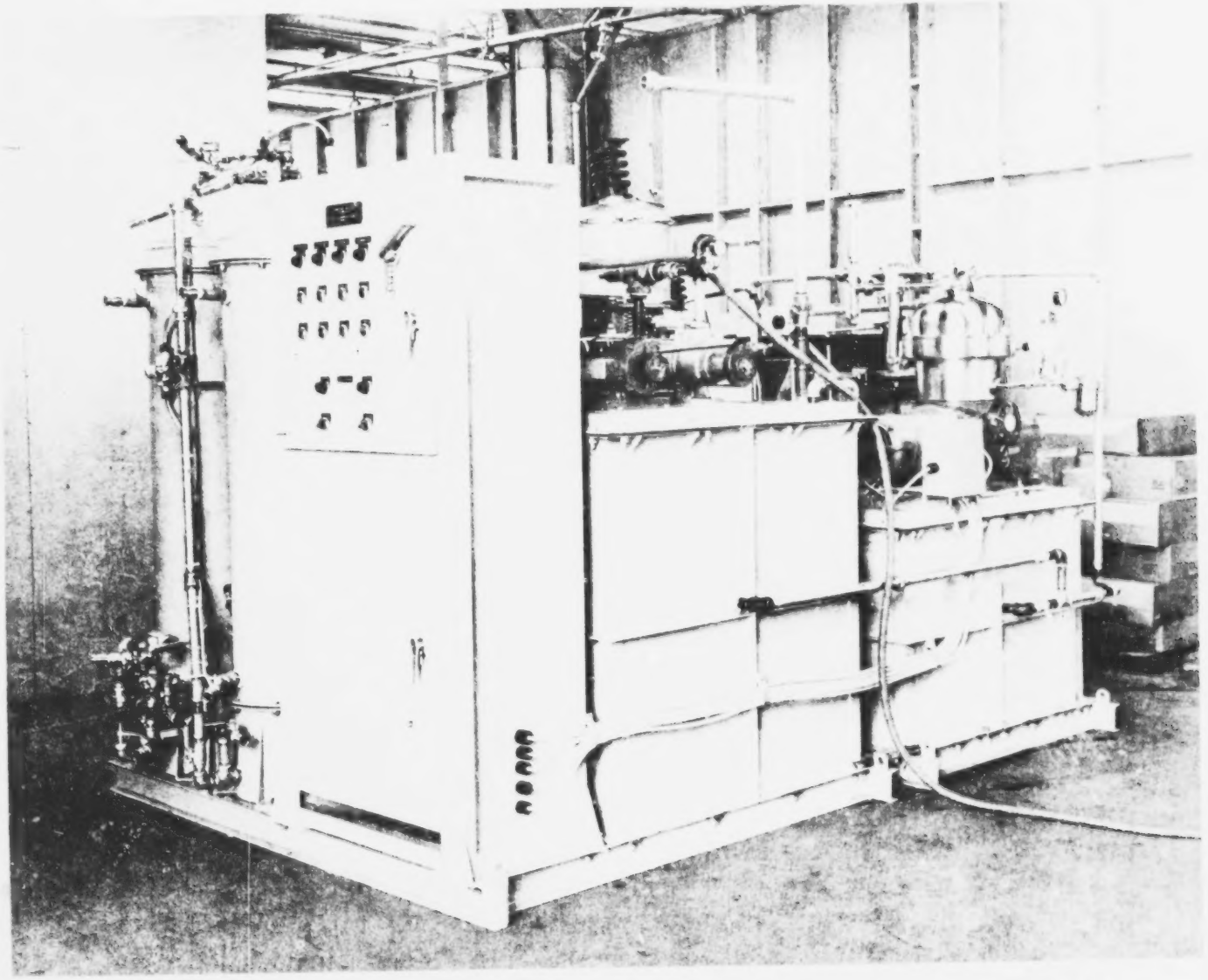


FIGURE 12: 4,000 GPD SYSTEM INSTALLED ABOARD S.S. MOBIL ARCTIC

SECTION VIII

ACKNOWLEDGEMENTS

Marland Environmental Systems, Inc. gratefully acknowledges the contributions made by the following persons to the successful completion of this program:

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a. Mr. Hal Bernard, who showed an early interest in the design of the Marland marine sanitation system and encouraged us to submit a demonstration grant application.

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2. The Delaware River and Bay Authority

a. The Board of Commissioners of the Delaware River and Bay Authority, for their interest in the program and their approval to make the Cape May-Lewes Ferry available as a test bed.

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3. Turbo Machine Company

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5. Dorchester Industries, Inc.

Mr. Robert Morgan, for supervision of the installation.

6. Marland Environmental Systems, Inc.

a. Mr. Joseph L. Cooperstein and Mr. John Bidrawn, for design, coordination, testing and evaluation of the system.

b. Miss Wendy Hilles, for administrative support and typing the manuscript of this report.

SECTION IX

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SECTION X

APPENDICES

APPENDIX A-1

MEASURED AND PREDICTED WASTEWATER FLOWS

Appendix A-1: Measured and Predicted Wastewater Flows

In order to estimate the capacity of the proposed marine sanitation system, select the system through-put flow rate, and size the various components of the system, flow measurements were made aboard the Cape May-Lewes Ferry on June 11, 1971, and on the basis of these flows and the passenger loadings, projections were made of the anticipated flows for the peak passenger day in 1972. Since it would have been practically impossible to measure the actual flow of wastewater from the vessel, measurements were made instead at the vessel's sanitary pump, which provides Delaware Bay water for flushing purposes and for auxiliary cooling, and at the fresh water pump. It was assumed that these flows would eventually be routed to the sanitation system.

The measured cumulative flows at both pumps for the eight trips made on June 11, 1971 are listed in Table A1-1. From these data the total flow for each trip and the total for the day were obtained and are listed in Table A1-2. The sanitary pump flows for trips No. 1 and No. 7 were estimates. On trip No. 1, it was discovered that most of the flow was being used for auxiliary cooling. Hence the sanitary pump flow for this trip was estimated, based on the passenger ratios, from trip No. 2. The sanitary pump flow for trip No. 7 was estimated because, for a 10-minute period, the pump was required for auxiliary cooling purposes. The flow for this period was assumed to be the same as the previous 10-minute flow. Table A1-2 shows that, for a total of 1,061 passengers, there was an estimated flow of 1,448 gallons, approximately two-thirds of which is flushing water and the remaining one-third fresh water (sinks, galley).

For the purpose of estimating the flow for the peak passenger day in 1972, the peak passenger day in 1970 (August 15, 1970) was used as a basis. The number of passengers carried on each trip and the total for the day are listed in Table A1-3.

In 1971 the Cape May-Lewes Ferry abandoned the practice of using a single vessel to make 10 trips in a single day, and adopted the 8-trip day shown in Table A1-1. Hence, the 10-trip passenger loading was adjusted by subtracting the passengers for the last two trips. As a result, the predicted peak passenger loading is 1972 would be 3,111. The ratio of this number to the June 11, 1971 number (1,061) is slightly less than 3. A factor of 3 on wastewater flow was adopted, which predicts a total flow (3 times 1,448 gallons) of approximately 4,400 gallons, that is, a nominally 5,000 gpd system. If it is assumed that this flow occurs over a 16-hour period (a 15-hour operating day plus approximately one hour to process the wastewater still accumulated in the collection tank at the end of the last trip), a system through-put flow rate of 5 gallons per minute is adequate. Higher rates would, of course, handle the wastewater flows more efficiently, but there are a number of reasons for selecting the lowest practical rate. First, the lower the flow rate, the more efficiently does the centrifuge separate suspended solids, which is a major consideration in the design. The lower flow rate also minimizes the size of the carbon columns and the disinfection tank, since the sizes of these units are governed by retention time. The lower flow rate does, however, maximize the size of the collection tank.

The required storage capacity for the collection tank was determined by plotting the flows from Table A1-1, multiplied by a factor of 3, and superposing the pump-out at a 5 gpm rate. The difference between the two ordinates represents wastewater accumulated in the tank. The process is illustrated in Figures A1-1 through A1-8, each representing a single trip.

The flow to the tank for the first trip (Figure A1-1) is shown by the solid line. From preliminary designs of the collection tank and level sensors positions, it was determined the pump emptying the tank would not start until the accumulated wastewater reaches a volume of 100 gallons, and that the pump will shut off when the volume is, for all practical purposes, zero. The pump-out at a rate of 5 gpm is shown dotted. It empties the tank at a time of 0850 hours, and at the end of the trip an accumulated volume of 25 gallons is left in the tank.

This figure becomes the base for the second trip. The tank is emptied at a time of 1000, and the pump doesn't start again until 1015. At the end of the second trip the accumulated wastewater is 175 gallons. This becomes the base for the third trip, and the process is repeated until the end of the day. From this procedure it was established that the maximum required storage capacity, which occurs in the fifth trip, is 520 gallons. A 600-gallon tank was designed to provide a margin of safety. Following docking at the end of the last trip, the sanitation system would continue to operate for 88 minutes until the collection tank is empty, at which time the system would begin automatically turning itself off.

TABLE A1-1

MEASURED CUMULATIVE FLOWS
AT SANITARY PUMP AND FRESH WATER PUMP
CAPE MAY - LEWES FERRY
JUNE 11, 1971

TRIP	NO. OF PASSENGERS	TIME	SANITARY PUMP FLOW (gals)	FRESH WATER PUMP FLOW (gals)	TOTAL FLOW (gals)	REMARKS
		0700	0	0	0	
		0710	70	0	70	
		0720	115	0	115	
		0730	200	0	200	Lv.N.J. 0735
1	49	0740	261	0	261	
		0750	325	34	359	Discovered
		0800	391	34	391	that most of
		0810	454	73	527	sanitary flow
		0820	527		600	was being
		0830	666		739	used for
		0840	728		801	auxiliary
		0845	801	91	892	cooling
		0850	-		-	
		0910	-		-	
		0920	1024		1115	Ar.Del. 0920

TABLE A1-1
(Continued)

TRIP	NO. OF PASSENGERS	TIME	SANITARY PUMP FLOW (gals)	FRESH WATER PUMP FLOW (gals)	TOTAL FLOW (gals)	REMARKS
		0920	1024	91	1115	Ar.Del. 0920
		0930	1035	111	1146	Lv.Del. 0935
					1149	
2	116	0940	1038		1152	
		0950	1041		1160	
		1000	1049	127	1187	
		1010	1060		1211	
		1020	1084		1227	
		1030	1100	151	1266	Ar.N.J. 1045
		1040	1115		1276	
		1050	1125		1287	
		1100	1136		1304	
		1110	1153		1306	
		1120	1155		1315	
		1130	1164			
					1317	Lv.N.J. 1135
3	134	1135	1166		1318	
		1140	1167		1339	
		1150	1188		1350	
		1200	1199	172	1382	
		1210	1210		1422	
		1220	1250		1440	
		1230	1268			

TABLE A1-1
(Continued)

TRIP	NO. OF PASSENGERS	TIME	SANITARY PUMP FLOW (gals)	FRESH WATER PUMP FLOW (gals)	TOTAL FLOW (gals)	REMARKS .
		1230	1268	172	1440	
		1240	1279	187	1466	
		1250	1300		1487	Ar.Del. 1250
4	179	1305	1270		1457	Lv.Del. 1305
		1310	1277		1464	Pump lost
		1320	1325		1512	prime at 1305
		1330	1335	217	1552	
		1340	1354	217	1571	
		1350	1371	242	1613	
		1400	1389		1631	
		1410	1396		1638	
		1420	1417	270	1687	
		1430	1421		1691	Ar.N.J 1430
		1440	1428		1698	
		1445	1432	277	1709	
5	111	1500	1447	277	1724	Lv.N.J. 1500
		1510	1453		1730	
		1520	1465		1742	
		1530	1495		1772	
		1540	1503	288	1791	
		1550	1506		1794	
		1600	1515		1803	

TABLE A1-1
(Continued)

TRIP	NO. OF PASSENGERS	TIME	SANITARY PUMP FLOW (gals)	FRESH WATER PUMP FLOW (gals)	TOTAL FLOW (gals)	REMARKS
		1600	1515	288	1803	
		1610	1526	307	1833	
		1620	1536		1843	
		1630	1540		1847	Ar.Del. 1630
		1640	1543		1850	
		1650	1569	323	1892	
		1700	1590		1913	
6	202	1705	1602		1925	Lv.Del. 1705
		1710	1621		1944	
		1720	1634		1957	
		1730	1643	335	1978	
		1740	1656		1991	
		1750	1671		2006	
		1800	1679	352	2031	
		1810	1694		2046	
		1820	1702		2054	Ar.N.J. 1820
		1830	1703		2055	
7	156	1840	1707		2059	Lv.N.J. 1840

TABLE A1-1
(Continued)

TRIP	NO. OF PASSENGERS	TIME	SANITARY PUMP FLOW (gals)	FRESH WATER PUMP FLOW (gals)	TOTAL FLOW (gals)	REMARKS
7	156	1840	1707	352	2059	Lv.N.J. 1840
		1850	1711	372	2083	
		1900	1717		2089	
		1910	1750		2122	
		1920	1763	377	2140	Flow for cooling
		1930	1837		2214	betw. 1920 &
		1940	1851		2228	1930
		1950	1855		2232	
		2000	1867	385	2252	Ar.Del. 2000
		2010	1861		2246	Pump lost
		2020	1866		2251	prime at 2010
		2030	1902	401	2303	
8	114	2040	1899		2300	Lv.Del. 2040
		2050	1907		2308	Pump lost
		2100	1916		2317	prime at 2040
		2110	1920	414	2334	
		2120	1938		2352	
		2130	1942		2356	
		2140	1958	461	2419	
		2150	1970	497	2467	
		2155	1970	497	2467	Ar.N.J. 2155

TABLE A1-2
MEASURED AND PREDICTED FLOWS PER TRIP
CAPE MAY - LEWES FERRY
JUNE 11, 1971

TRIP	TIME	NO. OF PASSENGERS	SANITARY PUMP FLOW (gal)	FRESH WATER PUMP FLOW (gal)	TOTAL FLOW (gal)
1	0730	49	(38)	91	(129)
2	0930	116	91	60	151
3	1130	134	185	36	221
4	1300	179	151	83	234
5	1500	111	119	30	149
6	1700	202	162	49	211
7	1830	156	(105)	33	(138)
8	2030	114	103	112	215
TOTALS		1061	(954)	494	(1448)

Notes: 1. Quantities in parentheses are estimates
2. Totals for each trip are from arrival to arrival (see Table A1-1)

TABLE A1-3

NUMBER OF PASSENGERS PER TRIP
PEAK PASSENGER DAY IN 1970
(AUGUST 15, 1970)

TRIP	TIME	NO. OF PASSENGERS
1	0630	144
2	0830	455
3	1030	380
4	1230	372
5	1430	411
6	1630	441
7	1830	533
8	2030	375
9	2230	436
10	0030	152
TOTAL FOR 10 TRIPS		3,699
MINUS LAST 2 TRIPS		- 588
TOTAL FOR 8 TRIPS		3,111

FIGURE A1-1
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 1

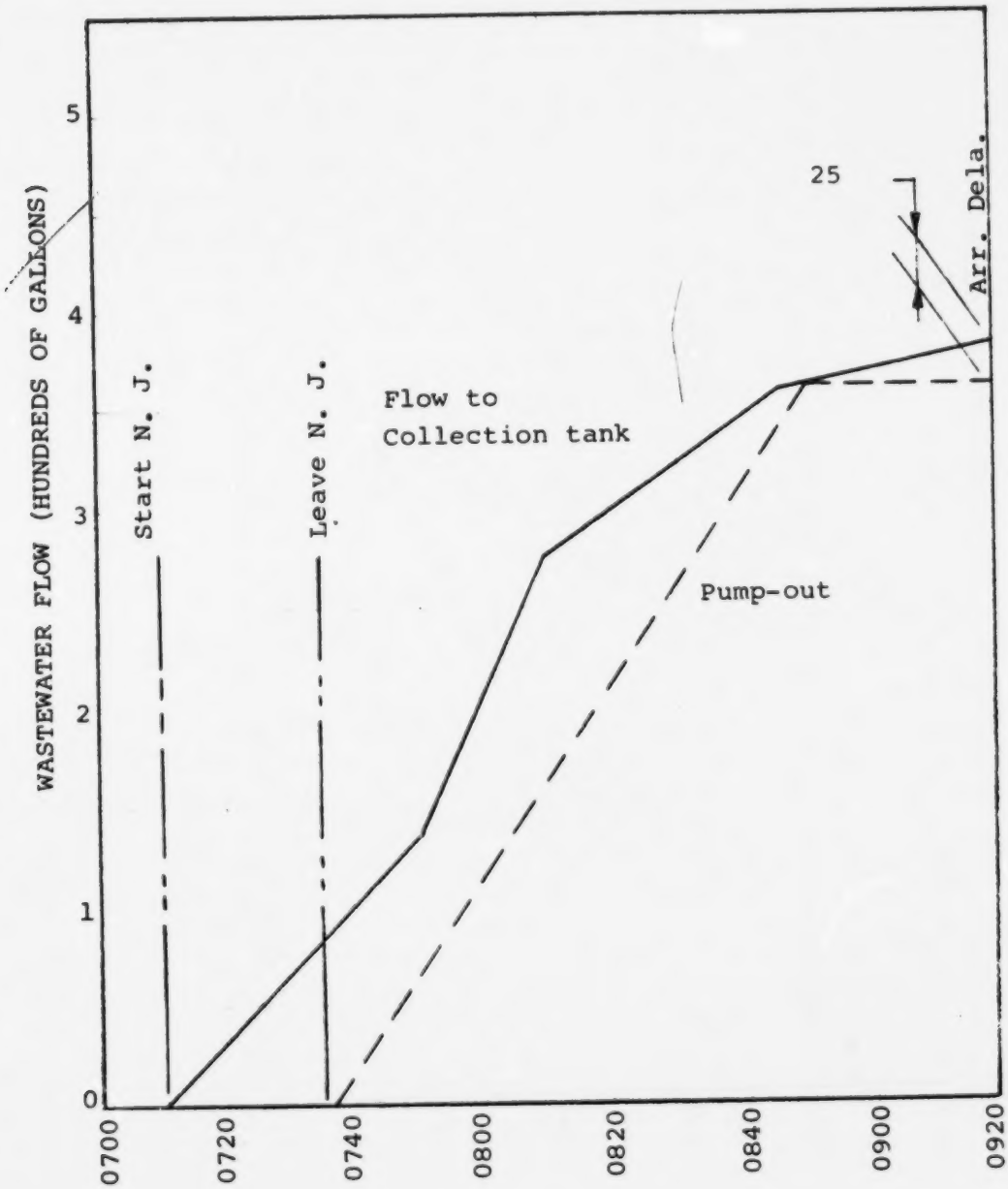


FIGURE A1-2
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 2

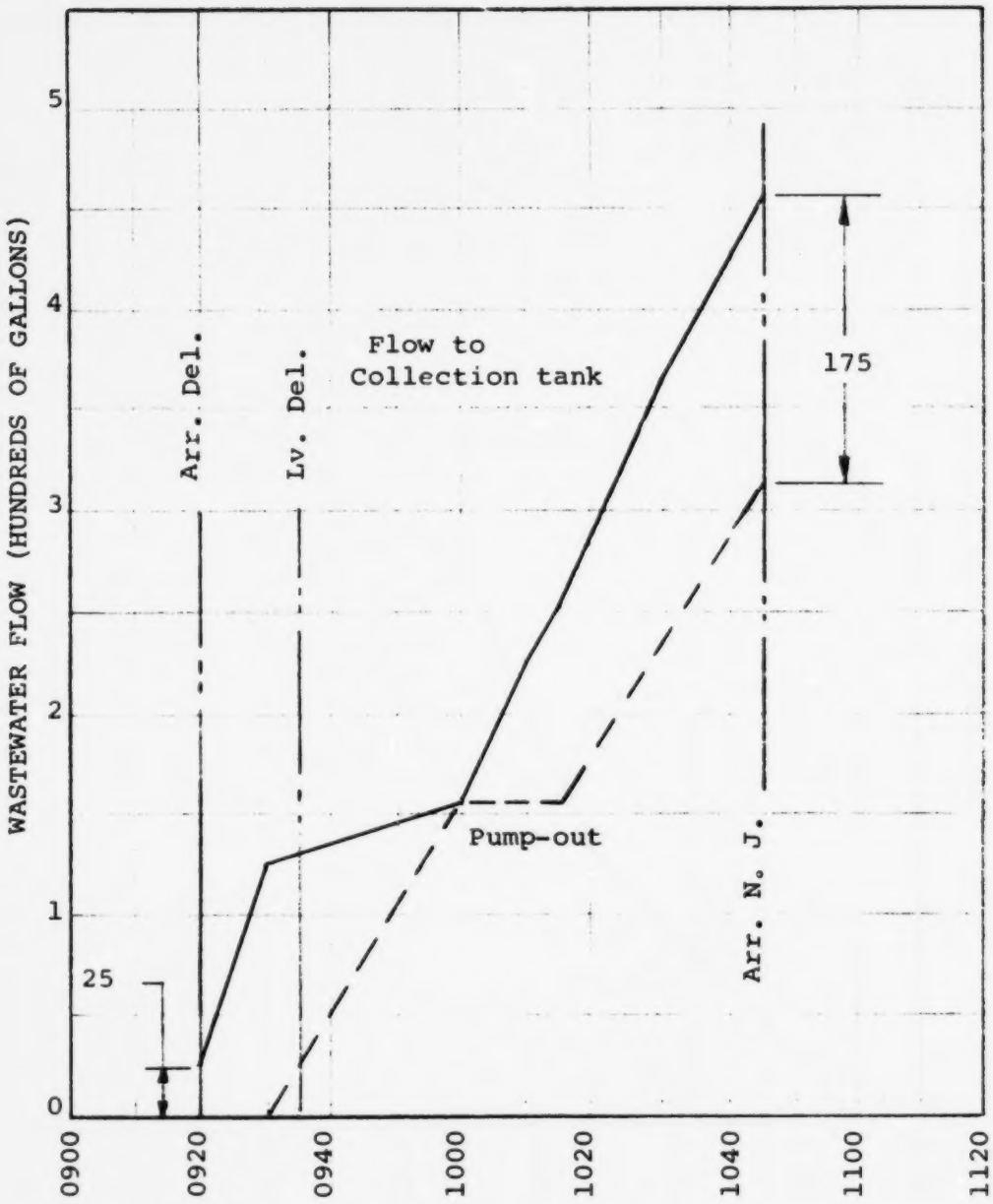


FIGURE A1-3
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 3

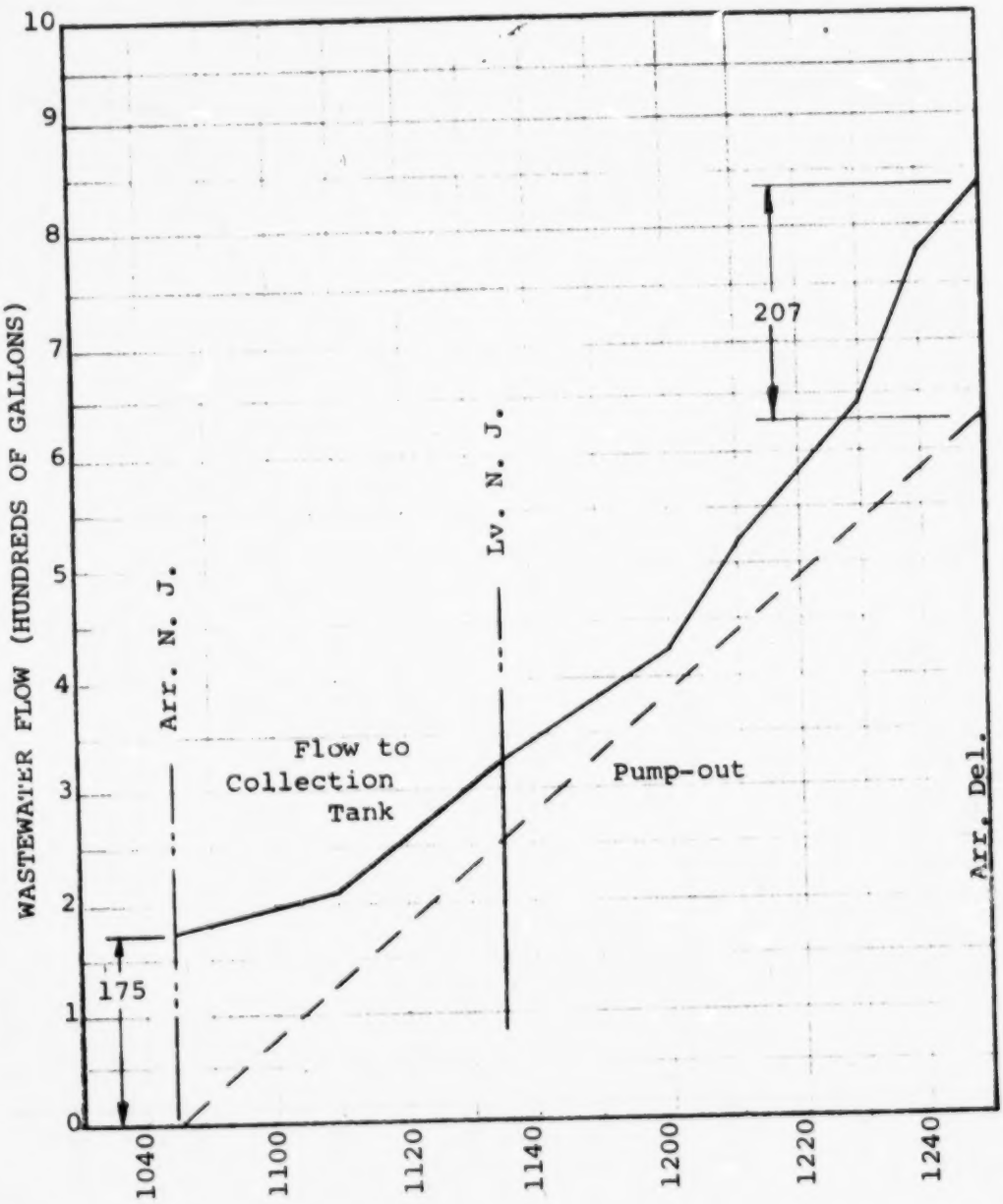


FIGURE A1-4
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 4

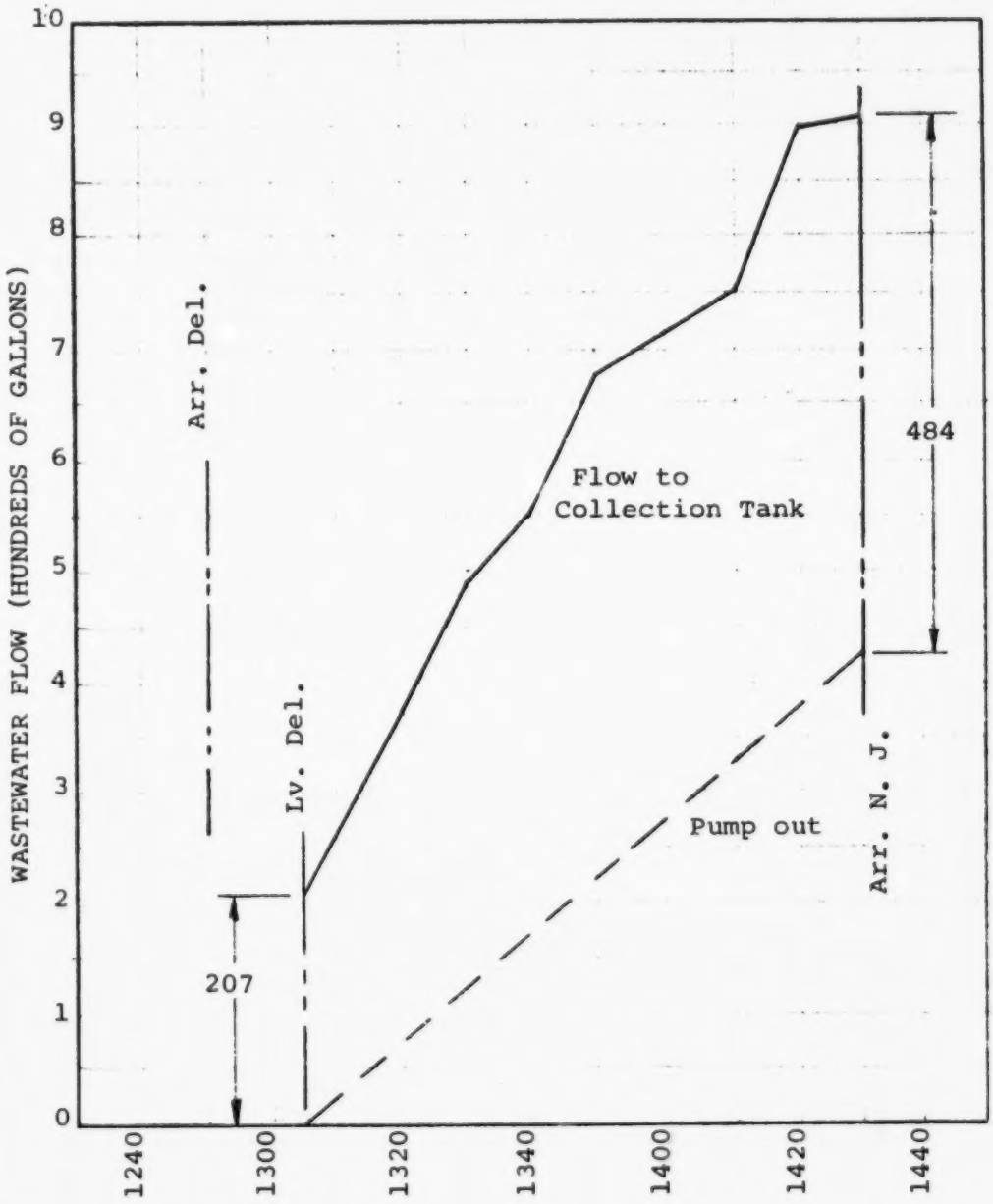


FIGURE A1-5
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 5

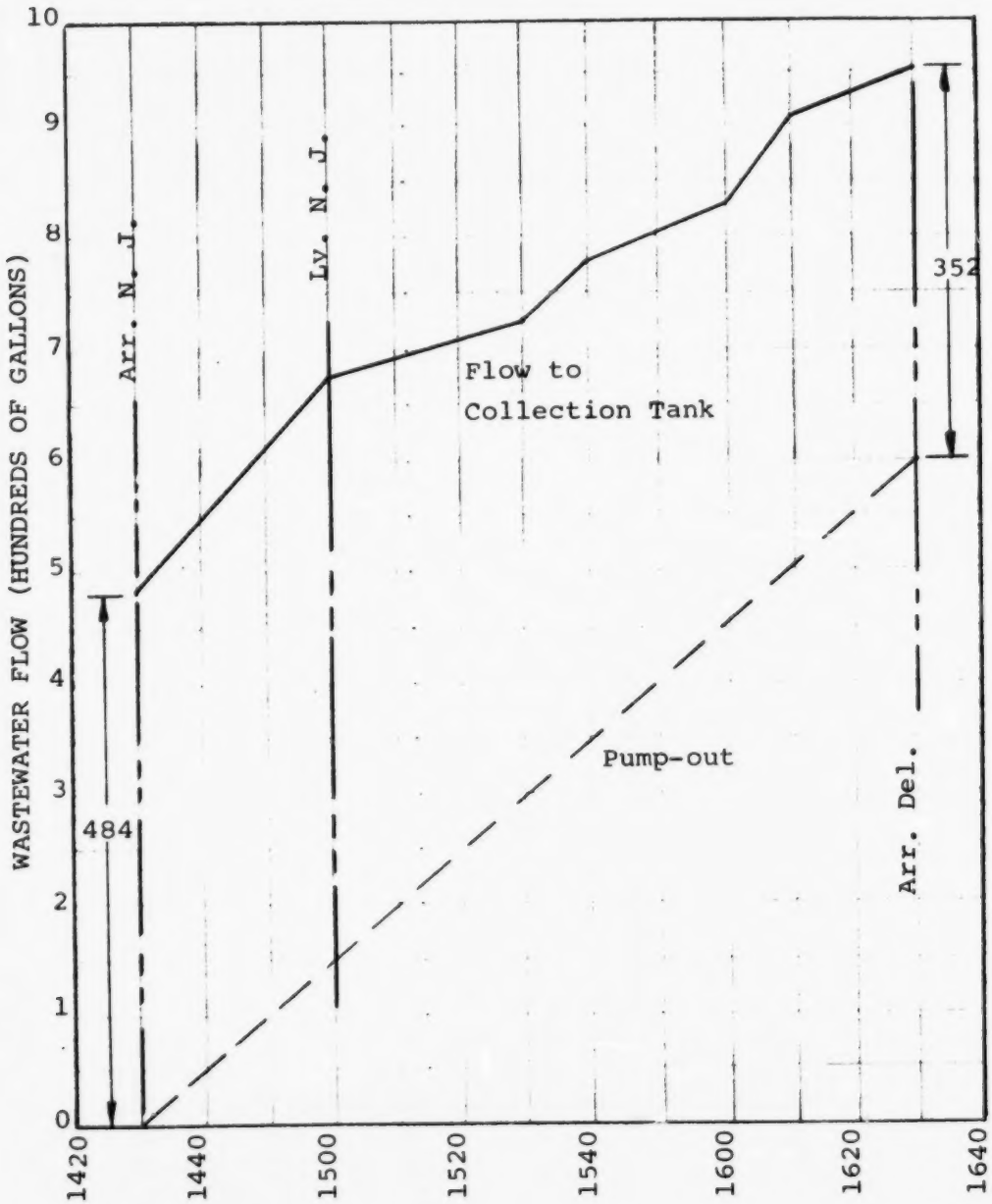


FIGURE A1-6
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 6

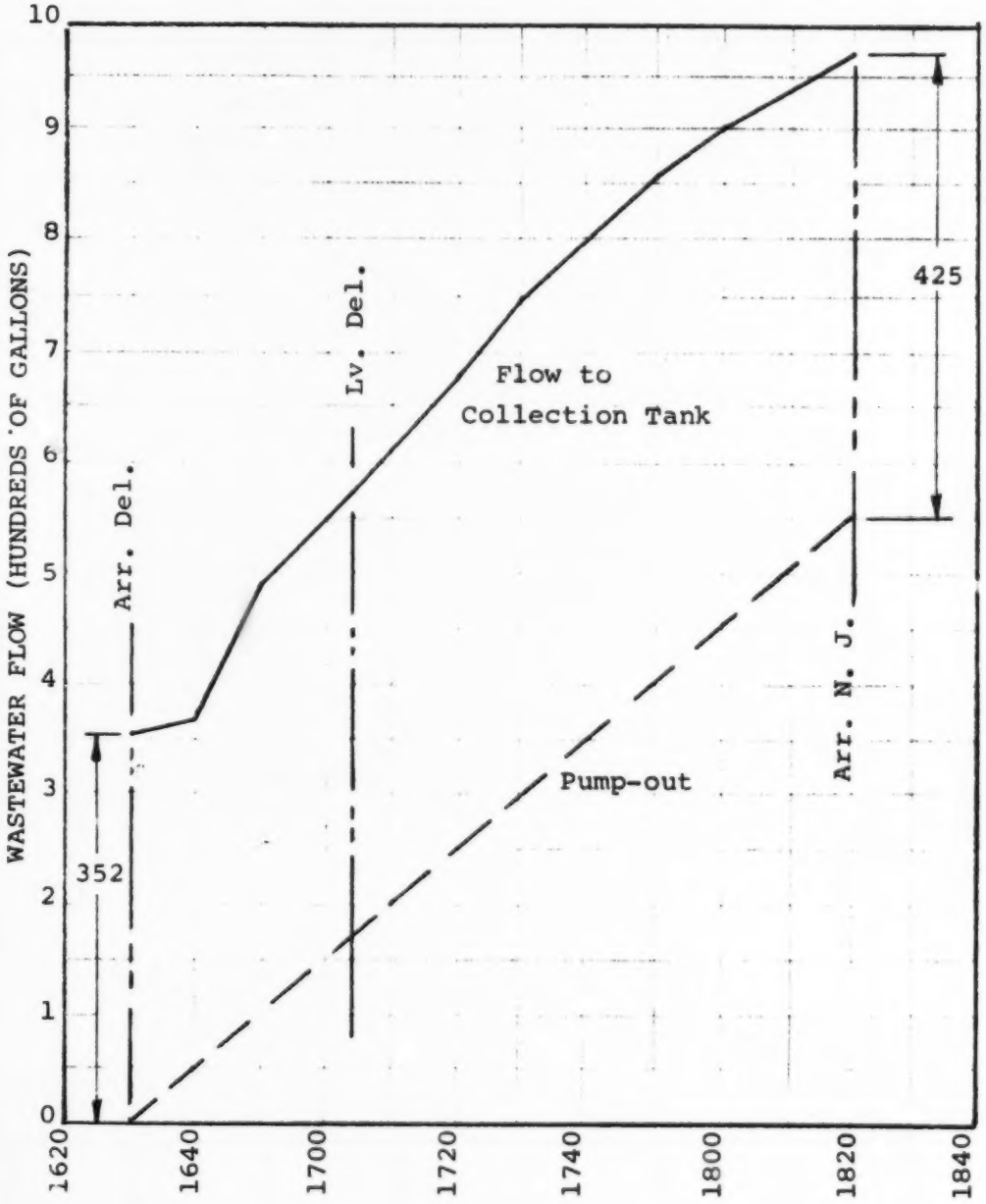


FIGURE A1-7
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 7

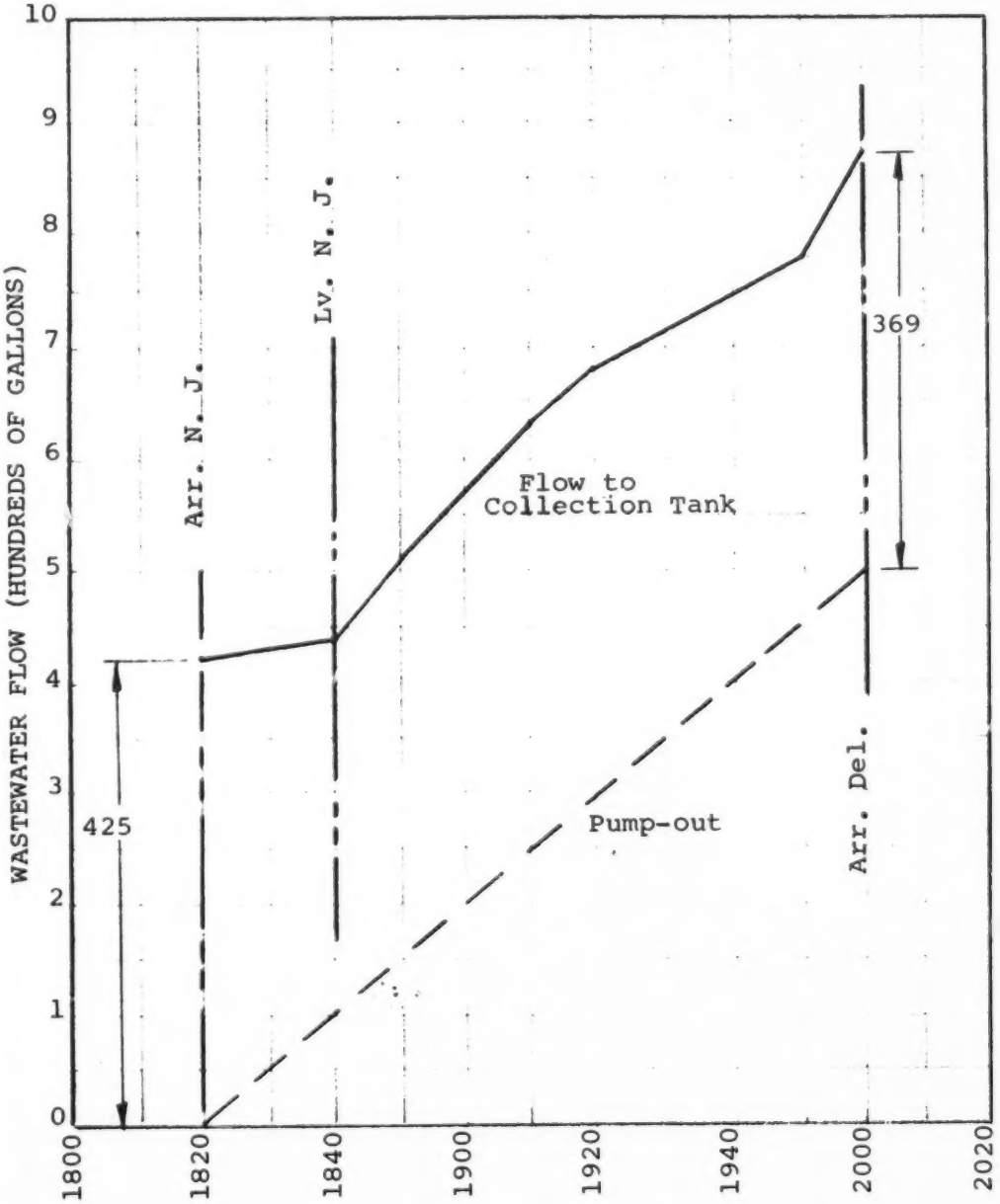
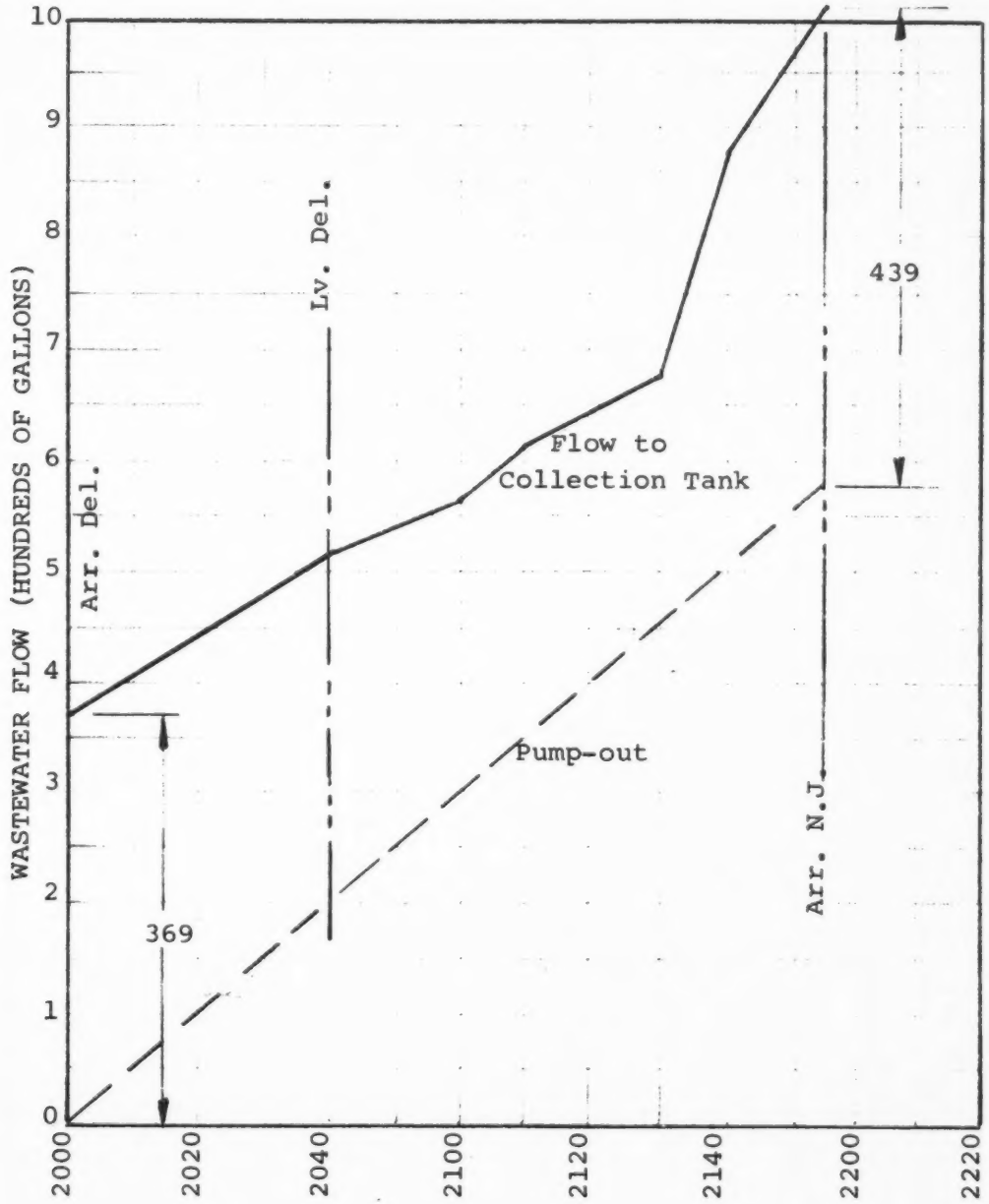


FIGURE A1-8
WASTEWATER FLOW DESIGN CURVE
CAPE MAY - LEWES FERRY
TRIP NO. 8



APPENDIX A-2

INITIAL SUSPENDED SOLIDS REMOVAL TESTS

Appendix A2: Initial Suspended Solids Removal Tests

The initial investigation performed on the program was an evaluation of the suspended solids removal capability of the system, using a comminuter and a Westfalia SA7-06 centrifuge. The comminuter was abandoned when it was found that the device did not remove fibrous material from the wastewater, which could lead to plugging of the centrifuge, especially when the suspended solids loading was high. The comminuter was removed from the system and its place was taken by a SWECO vibro-separator, which eliminated the plugging problem completely.

Difficulty was encountered in obtaining the correct type of sewage for test purposes. Since the toilets aboard the vessel discharge directly into the treatment system, the sewage should be fresh. Sewage from various facilities was tested until an appropriate sewage was found at an apartment complex called English Village Apartments. Sewage for test purposes was collected, on the morning of the test, immediately upstream of the comminuter/bar screen of the apartments' package wastewater treatment plant.

Sewage from the following sources was rejected for the reasons given below:

1. 7-Eleven Store - Septic sewage, held too long (12 days usually).

2. Hatfield Municipal Treatment Plant - Sewage was only able to be drawn from point where coagulation chemicals were recycled to the inlet to the treatment facility.

3. Jiffy Jon portable toilet pump outs - Chemical additives to reduce odor in the portable toilets affected the character of the sewage solids with regard to turbidity and surface tension (caused foaming).

4. Fort Washington Industrial Park - Chemical additives used to clean a milk plant in the industrial park were detected by odors, and soluble milk solids contributed milk sugars which were not absorbable by activated carbon.

5. Eastern Baptist College dormitory - Septic sewage, by the configuration of their existing piping and sewage draw point.

The results of all suspended solids removal tests conducted with the prototype system are presented in the following table. Except for some high values in the centrifuge effluent with high suspended solids in the feed, the removals are generally satisfactory.

TABLE A2-1
PROTOTYPE SYSTEM
SUSPENDED SOLIDS LEVELS (MG/L)
FLOW RATE OF 5 GALLONS PER MINUTE

RUN NO.	SOURCE	F	SU	CE	CCE
1	7-Eleven Store (7-30-71)	310	-	48	-
2	Hatfield Municipal Sewage Plant (8-11-71)	VERY HIGH SOLIDS, PLUGGED CENTRIFUGE			
3	(8-20-71)	5600	4860	375	-
4		2920(D)	-	198	-
5		3820(C)	-	197	-
6		3870(C)	-	102	-
7	(8-20-71)	3720(C)	-	112	-
8	(8-26-71)	2380	1367	-	-
9		900	-	62	-
10		1375	-	16	-
11		1060	-	48	-
12		1025(C)	-	72	-
13		712(C)	-	52	-
14	(8-26-71)	1083(C)	-	60	-
15	Jiffy Jon Portable Toilets (9-1-71)	Chemical additives used in the toilets to prevent excessive odors caused foaming & the overall dark brown color was highly turbid both before & after centrifuging. No samples analyzed.			

NOTE

C means chemical addition prior to centrifuging
D means dilution

TABLE A2-1 (Continued)
PROTOTYPE SYSTEM
SUSPENDED SOLIDS LEVELS (MG/L)
FLOW RATE OF 5 GALLONS PER MINUTE

RUN NO.	SOURCE	F	SU	CE	CCE
16	Ft. Wash. Ind. Park (9-10-71)	380?	860	68	80
17		438	-	48	-
18		640(C)	-	50	-
19		770(C)	-	76	-
20	(9-10-71)	95(C)	-	25	-
21	(9-27-71)	120	430	104	-
22	(9-30-71)	230	112	56	48
23	(10-4-71)	304	332	122	82
24	(10-7-71)	564	436	148	-
25	(10-7-71)	564(C)	544	244	37
26	Eastern Baptist (10-12-71)	198	-	19	-
27	English Village (10-19-71)	482	348	27	12
28	(10-20-71)	106?	172	17	16
29	(10-21-71)	144	78	47	10
30	(10-28-71)	306	172	20	10
31	(11-3-71)	648	290	46	11
32	(11-17-71)	124	75	20	9
33	(11-18-71)	360	148	26	10
34	(12-2-71)	130	120	5	2.3
35	(12-13-71)	434	282	67	18
36	(1-18-72)	258	256	45	24
37	(1-19-72)	132	124	38	4

NOTE

C means chemical addition prior to centrifuging
D means dilution

APPENDIX A-3

MARINE SALTS

Appendix A-3: Marine Salts

For simulated salt water tests with the prototype system, Aqua-Biotics Marine Salts, distributed by Aquarium Pharmaceuticals, Inc., were used. Using one pound of salt for each three gallons of fresh water, each liter of solution will contain the following:

Manganese Sulfate	3.950 mg.
Disodium Phosphate	3.290 mg.
Lithium Chloride	0.987 mg.
Sodium Molybdate	0.987 mg.
Calcium Gluconate	0.658 mg.
Potassium Iodide	0.095 mg.
Potassium Bromide	0.029 mg.
Aluminum Sulfate	0.475 mg.
Cobalt Sulfate	0.053 mg.
Rubidium Chloride	0.157 mg.
Strontium Chloride	19.700 mg.
Copper Sulfate	0.448 mg.
Zinc Sulfate	0.101 mg.
Sodium Chloride	27.500 Gm.
Magnesium Chloride	5.380 Gm.
Potassium Chloride	0.722 Gm.
Sodium Bicarbonate	0.200 Gm.
Magnesium Sulfate	6.770 Gm.
Calcium Chloride	1.375 Gm.

APPENDIX A-4

NITROGEN LEVELS IN DOMESTIC WASTEWATER

Appendix A-4: Nitrogen Levels in Domestic Wastewater

It was mentioned in Section VI of this report that the ammonia nitrogen levels measured in recycled wastewater aboard the Cape May-Lewes Ferry (50 to 460 mg/l) were an order of magnitude higher than the levels in domestic wastewater. The basis for comparison was performance data obtained for two 10,000 gpd land-based biological wastewater treatment plants by the Aquatair Corporation of Dayton, Ohio, an affiliate of the Mead Corporation. A typical Aquatair plant consists of the following sequence of tanks: a sludge holding tank, a recirculation chamber on top of which is mounted a plastic media trickling filter, a secondary clarifier, and a chlorination chamber.

Performance data for the two plants are listed in Tables A4-1 and A4-2. In order to give an overall picture of performance, suspended solids and BOD_5 data are listed, in addition to the nitrogen data. The Moose Lodge plant (Table A4-1) handles kitchen wastes, showers, toilets and urinals, and wash basins. The Alexandria Township School plant (Table A4-2) handles the wastewater for an elementary school. The ammonia nitrogen in the influent is 21.80 mg/l for the Moose Lodge plant and 14 mg/l for the school plant. These values are roughly an order of magnitude lower than the ammonia nitrogen values obtained during the recycle tests aboard the Cape May-Lewes Ferry.

The performance data for the two plants also show that ammonia can be removed from the wastewater by biological nitrification.

TABLE A4-1

PERFORMANCE DATA
AQUATAIR BIOLOGICAL WASTEWATER TREATMENT PLANT
MOOSE LODGE
KINGSPORT, TENNESSEE

PARAMETER	INFLUENT	EFFLUENT
Suspended Solids	186	24
BOD_5	1066	15
Nitrogen		
NO_3-N	0.23	12.11
NO_2-N	0.02	0.04
Organic N	12.88	2.18
NH_3-N	21.80	1.02
Total-N	34.94	15.35

NOTES

(1) All values in mg/l

(2) 10,000 gpd system

TABLE A4-2

PERFORMANCE DATA
AQUATAIR BIOLOGICAL WASTEWATER TREATMENT PLANT
ALEXANDRIA TOWNSHIP SCHOOL
EVERETTSTOWN, NEW JERSEY

PARAMETER	INFLUENT	EFFLUENT
Suspended Solids	500	50
BOD_5	180	16
Nitrogen		
NO_3-N	0.2	7.8
NO_2-N	0.01	0.03
Organic-N	76	11.0
NH_3-N	14	4.2
Total N	90	23.0

NOTES

(1) All values in mg/l

(2) 10,000 gpd system

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